University Transportation Research Center - Region 2

Final Report

Port Resilience: Overcoming Threats to Maritime Infrastructure and Operations From Climate Change

Performing Organization: Stevens Institute of Technology

December 2015

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.

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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

In the coastal zone, seaports and their intermodal connectors are key types of infrastructure that support the global supply chain, provide regional economic activity, local transportation system services, and community jobs. The protection of coastal communities and their ports has been taken for granted during a prolonged period of climate stability. Recently there are growing concerns that a new period of climate change and severe weather events is emerging. Communities and their waterfront facilities are vulnerable to disruptions. Enhancing coastal resilience has become an important response to these events.

The objective of this research is to move from the aspirational concept of resilience to a standardized framework for creation of resilience in ports and transportation systems by integrating physical infrastructure and social systems. It takes a fully functioning maritime and shore-side distribution system for successful supply chain operations. A combination of stakeholder interviews and workshops provided insights into the resilience processes. It was discovered that every coastal community is unique and typically has its own plans. The same can be said of their coastal ports as well as the individual supply chain service providers associated with those ports. On the physical infrastructure side, it was found that a more resilient coastline can be achieved through the adoption of consistent, coordinated, and forward thinking building codes. One of the challenges to adopting more stringent design standards was the uncertainty surrounding future conditions. Another recommendation of the study involves the suggestion for port regions to organize along the entire supply chain including transport and distribution activities beyond local marine terminals. A suggested organizational scheme is proposed with coordinating bodies at the regional and state level that would interact with local port waterside and landside logistics teams prior to, during, and after a supply chain disruption.

Resiliency processes and approaches used to reduce consequences of sea level rise, coastal flooding or other disruptions at ports and coastal communities cannot be fully treated with a single comprehensive framework or guidelines because of the unique characteristics of each situation and the involved community and their port facilities. However stakeholder organizations can build social capital by working and training together, ultimately improving port and supply chain resilience.

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1. Introduction

The United States (U.S.) is served by the global freight transportation system; a system that is a demand-derived service for people and goods seeking to move from one point to another for business and pleasure purposes (MARAD, 2015). Since approximately 70 percent of the planet is covered by water, waterborne transport is an important component of the overall system. Although global economic growth was weak in 2013, today's maritime transportation is a significant contributor to the prospects for continued improvement in the world economy (UNCTAD, 2014). The U.S. economy, measured by gross domestic product (GDP), increased by ~68 percent in real terms (inflation adjusted), while household income, another indicator of economic growth, remained the same between 1990 and 2011. Nevertheless, foreign trade grew faster than the overall economy, doubling in real value over the same period, reflecting unprecedented global interconnectivity (Strocko, Sprung *et al.*, 2014). The backbone of this growth was the enormous expansion of global trade and transportation services, particularly maritime carriage (IMO, 2015).

In the coastal zone, seaports and their intermodal connectors are key types of infrastructure that provide transportation system services, community jobs, and regional economic activity. They are a foundational part of many coastal communities, which depend on their port infrastructure to connect them with other global destinations (AAPA, 2015). Ports were historically thought only of as locations where vessels could load and discharge cargo; they were not considered as transportation providers but only as the interface between the land and the sea. The focus was on the cargo vessel and the local navigation infrastructure, i.e., jetty, quay, pier, berth, and so forth. The cargo was another matter, being owned by some independent shipper with only a mind to getting their goods to market and making a profit. Today's ports are a critical part of a global freight pipeline that annually moves billions of dollars of cargo from one location to another or, as it is more commonly known, the global supply chain (Notteboom and Rodrigue, 2010).

1.1 <u>**Growing Concerns over Climate Change**</u>

Protection of coastal communities and the working waterfront has been taken for granted during a prolonged period of climate stability. Recently there are growing concerns that a new period of rapid, even abrupt, climate change is emerging with anticipated global increase in greenhouse gases (NRC, 2013). There were eleven weather and climate disasters in the United States in 2012 that caused more than $1 billion in damages each (National Climate Data Center, 2013). The most damaging event was Hurricane Sandy, which caused approximately $65 billion in damages and claimed 159 lives. Hurricane 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. But Hurricane Sandy, or as it was later called Super Storm Sandy after it made landfall, was not the only recent natural disaster causing significant physical and economic harm. 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).

Guaranteeing the vitality and sustainability of the coastal zone environment as well as the maintenance of commercial services requires an understanding of human populations and their behaviors, adequacy of protective infrastructure, and decision-making processes in stressed situations. Increasingly the coastal environment is being modified by the built environment including ports, residential areas, and shoreline facilities – particularly as the urban density increases along the shoreline (Becker, Inoue *et al.*, 2011;USACE, 2015). Furthermore the evidence for increasing sea level rise, even accelerating sea level rise, is appearing more frequently in the literature (Jevrejev, Moore *et al.*, 2014).

Recently both natural and human systems are being severely impacted by extreme coastal events including sudden flooding, coastal erosion, economic damages, and loss of life (Rhodium Group, 2014). Recent examples of these catastrophic events include Hurricane Sandy in the United States and Typhoon Haiyan in the Philippines. Coastal populations have depended on coastal infrastructure systems to protect their assets (USACE, 2015). Seawalls and other fortification measures have been used for centuries to hold back the water and protect coastal communities. But more recently the frequency of overtopping events has increased (NRC, 2014). The seemingly increasing occurrence of extreme events (from all-hazards) has further sharpened the public's desire to be able to understand and to predict decision-makers behavior in these stressful situations and occasionally life threatening situations. For example, many of the Port of New York and New Jersey's facilities were significantly damaged, and the entire port was closed for a week costing billions of dollars (Sturgis, Smythe *et al.*, 2014). The storm was anticipated for many days. How did this magnitude of damage occur and what can be done to make the port and its supportive intermodal infrastructure more resilient prior to another major storm?

Resiliency is an important capability of natural and human communities to endure (NRC, 2011). Recent studies of lessons learned following Super Storm Sandy (henceforth referred to as "Sandy") for port resilience highlighted the essential nature of social linkages and shared culture between the impacted individuals in enabling their successful restoration of maritime services in the Port of New York and New Jersey (Smythe, 2013;Sturgis, Smythe *et al.*, 2014;Wakeman and Miller, 2013).

1.2 **Defining Resilience**

The term resiliency comes from the Latin word "*resilire*" meaning "to leap back". Resiliency in common usage is often extended to mean the ability of a system or enterprise to "bounce back" after a disturbance (Omer, 2010). In Merriam-Webster's on-line dictionary (Merriam-Webster, 2015), "resilience" is defined as 1) the capability of a strained body to recover its size and shape after deformation caused especially by compressive stress, and 2) an ability to recover from or adjust easily to misfortune or change. Both definitions are in use but often in different disciplines. For example, in material science, resiliency is the ability of a material to absorb energy when deformed elastically and return to its original shape when it's unloaded. On the other hand, in psychiatry, it is the ability of an individual to withstand stresses and to recover from a traumatic life situation. This definition reflects the thinking of Canadian ecologist C.S. Holling, who described the difference in how engineers define the term and how scientists think of resilience in the mid-1990s (NRC, 1996). For engineers, resilience is the time to recover following a disturbance to some prior state or condition whereas ecological (or psychological as above) relates to the amount of disruption (or stress) a system (or person) can absorb before it (or they) changes state.

According to the National Research Council, resilience is the ability to absorb, adapt to, and/or rapidly recover from a potentially disruptive event (NRC, 2012). With respect to transportation infrastructure it is generally quantified as a dimensionless quantity representing the rapidity of the system to revive from a damaged condition to the pre-damaged functionality level (Banerjee, 2014). For the purposes of this document, disaster resilience is defined as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events," and that "enhanced resilience allows better anticipation of disasters and better planning to reduce disaster losses – rather than waiting for an event to occur and paying for it afterward" (Cutter, Ahearn *et al.*, 2013;NRC, 2014). Banerjee states that system performance during a natural disaster (commonly referred to as system vulnerability), resulting losses, and post-event system recovery are the three major components used to quantify the disaster resilience of a civil infrastructure system (Banerjee, 2014).

There is a great deal of literature on the subject of resiliency that comes out of the security activities that have been underway since the attacks of 9/11 and before (Davis, 2008). In port security, the definition is extended to include the ability of a port to return to its normal mode of operation after a disruption caused by a natural or man-made attack (Mansouri, Nilchiani *et al.*, 2010). However, the literature is somewhat limited regarding specific resiliency processes for ports and requires additional investigations, new case studies, and multi-discipline analyses (Madhusudan and Ganapathy, 2011;Southworth, Hayes *et al.*, 2014).

Some authors propose that the answer is partly a matter of applying risk assessment and management protocols (Hollnagel, Woods *et al.*, 2007). There are three fundamental characteristics of the risk assessment as described by the Department of Homeland Security (NRC, 2010):

- Risk is a product of threat, vulnerability and consequence.
- Probability (or likelihood) is a function of threat and vulnerability.
- Vulnerability is a function of accessibility, ability to detect and deter an incident, and the degree of 'hardness' or ability to withstand an attack.

Resilience engineering, as defined by Hollnagel, Woods *et al.* (2007), is one engineering response to desires for risk assessment and management. But risk and resilience can be defined in many different ways depending upon the system being addressed (Brooks, 2003;Omer, 2010). Resilience in business terms can be defined as the ability of an organization, resource or structure to sustain the impact of a business interruption and to recover, resume its operations and provide at least minimal services (SANS Institute, 2002;Sheffi, 2007). In terms of infrastructure resilience, it is the ability to reduce the magnitude, impact, or duration of a disruption (Olsen, 2015)**.**

1.3 **Port/Supply Chain Resiliency**

Today's port is no longer an isolated node but instead is an integral part of the global logistics system or 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. Each component of the supply chain, including the oceangoing vessels, ports and their terminals, and intermodal service providers, are equally responsible for the success of the international product being delivered (Mansouri, Nilchiani *et al.*, 2010). To protect the nation's economic security, it is important to know how the global marine transport system operates and sources of competitive capacity improvements in both public and private enterprises (DHS, 2013;FMC, 2015). Importantly, it is also essential to consider mechanisms for the enhanced business recovery post disruption and how to organize efforts across the system to restore commerce continuity quickly and effectively (Barnes and Oloruntoba, 2005).

The objective of supply chain resiliency is to maintain the business continuity of the supply-chain network. Business continuity refers to the activities required to keep an organization running during an interruption of normal operations; whereas, disaster recovery is the process of rebuilding an operation or infrastructure after the disaster has passed (SANS Institute, 2002). Business continuity depends on a management process for developing a set of advance procedures that when activated will enable the organization to restore its operational capacity after a disruption or series of disruptions. These procedures must allow critical business areas to function as soon as possible after the disruptive incident(s). Hence it becomes important to first identify critical infrastructure elements that are crucial and establish the key activities or resources needed to recover these infrastructure services immediately after a disruption and to regain business operations. In this context, the intention of business continuity activities is nearly identical to the intention for pre-event resilience activities.

2. Research Context

In engineering management, it was found that the modification of design and construction codes for coastal infrastructure and to protection of ecological assets must evolve from interagency agreements and collaborative behaviors among the coastal communities (USACE, 2015;Wakeman, 1997a;Wakeman, 1997b). Engineers, physical scientists, and social scientists must work together to create new physical infrastructure and social asset pairings that will enhance collaborative and cooperative behaviors before and after disruptive events (Olsen, 2015;Wakeman, 1997b). How can these disciplines work together to build a new and more effective approach to disruptive events at coastal ports?

The objective of this research project is to move from the aspirational concept of resilience to a standardized framework that has a normative protocol for creation of resilience in communities and transportation systems, particularly maritime systems. The strong human relationships were key to recovery following Sandy as well as other disruptive events, as has been reported (Klinenberg, 2013). Recent studies of the Port of New York and New Jersey demonstrated the important of human behavior in the success of resilience and restoration of marine services (Smythe, 2013).

2.1 **<u>Risk of Climate Impacts</u>**

Climate change is an increasing concern (NCDC, 2013; NRC, 2013). The questions of how to frame climate-related risk assessment and management processes to fully address resiliency strategies and to prepare for climate disaster response at urban communities and ports as well as the supply chains are important. Unfortunately, as mentioned earlier, there are a limited number of research publications on this topic probably because of lack of funding. Research can be expensive, and research programs to investigate future risks (such as climate change) are often postponed because of higher priorities. However the potential economic consequences of climate change are being estimated and business and community impacts forecasted. As the former Mayor of New York City, Michael Bloomberg said:

> ”Damages from storms, flooding, and heat waves are already costing local economies billions of dollars—we saw that firsthand in New York City with Hurricane Sandy. With the oceans rising and the climate changing, the Risky Business report details the costs of inaction in ways that are easy to understand in dollars and cents—and impossible to ignore.”
>
> — Risky Business Project Co-Chair Michael R. Bloomberg (Rhodium Group, 2014)

Fortunately the University Transportation Research Center, Region 2, felt that the issue deserved examination, particularly after Sandy closed the port to maritime activity, and provided funding to support this investigation.

2.2 **Test Hypothesis**

To help focus the investigation, a test hypothesis was developed, assumptions were listed as were research questions to consider during the conduct of the study. These are presented below:

Test Hypothesis:
There is an integrated framework/guideline integrating physical infrastructure and social capital that can be universally followed to help create urban coastal resilience, specifically in the coastal port setting, and to support business continuity and supply chain functions following a disruptive event. Further, there is the ability to use this framework/guideline to development resilience enhancing protocols and tools that are generally applicable to all port decision makers.

Assumptions:

1. Physical and non-structural infrastructure (e.g., wetlands, oyster beds, etc.) are essential to the protection of the urban coastal zone.
2. Human capacity to respond to disruptive changes in the environment and to react constructively and collaboratively are foundational for community resilience.
3. A synthesis of these two characteristics can lead to a conceptual framework that is implementable by application of a normative protocol.

Research Questions:
First, are there specific physical/social resilience assets that are essential underpinnings for infrastructure resilience and business/community continuity following a disruption? If so, what are these elements in the context of a physical/social framework/guideline, and how do we proceed with their development and implementation? Second, if a framework/guideline can be described, how should decision makers prioritize their activities and resources to best address community concerns as well as port services restoration under this framework/guideline?

2.3 **Research Approach**

There are many case studies in the literature, mainly describing the concept of resilience and the specific *ad hoc* activities of their particular case (Amoaning-Yankson, 2013;NIST, 2015;NRC, 2012). It is important to move from descriptive concept of resilience to a normative agenda to make decisions more consistent and universal (Weichselgartner and Kelman, 2014). This project's intention is to examine processes for enhancing resilience and recovery and to expand the understanding of the social contributions (such as collaboration and cooperation) with respect to resilience practices. The results may also help illuminate emerging issues regarding coastal infrastructure-social linkages in the face of changing environmental conditions, natural and human-caused hazards, and urban coastal sustainability. Also these results may be applied to modifying design and building code standards for coastal infrastructure and network industry organizational factors to enhance coastal zone adaption to sea level rise and ecosystem sustainability, particularly in coastal urban environments.

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 (NRC, 2009). 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? Further, warnings of increased vulnerability of these lifeline systems to communities cause unintended consequences including runs on stores, hoarding, and in the extreme, general panic among residents. Clearly there are interdependencies between network industries and failures that must be further investigated. This study seeks to identify linkages and contribute to that body of knowledge.

In addition to research on network infrastructure systems, the project also attempted to address the need for more research that is cross-cutting and attempts to align engineering methodologies and social science findings to enhance resilience practices. The limited body of work (Wakeman and Miller, 2013; Smythe, 2013) on the importance of social capital in recovery of the Port of New York and New Jersey following Sandy needs augmentation to allow identification of mechanisms to build resilience and ultimately sustainability in communities. Further attention to this area is also warranted. This attempted to build on the earlier work in New York Harbor.

3. Infrastructure Systems

3.1 **Physical Infrastructure**

The high value and volume of commercial goods moved into and out of the United States on the water make maritime ports indispensable (MARAD, 2015). Ports inherently have some level of vulnerability to a disruptions because of their location (adjacent to waterways), the physical state of their facilities (new, old, etc.), and their interdependencies with their specific industrial and societal counterparts. Typically the impacts from a port disruption have been managed with minor consequences. However, it appears that with Sandy and other recent storms on the Eastern seaboard, combined with future trends of sea-level rise and increasing storm severity, are making activities to reduce the impact of port flooding and facility damages an economic necessity.

One of the issues that has made urban waterfronts in general, and ports specifically, more vulnerable is the lack of consistent engineering design guidance. Perhaps the best example is the lack of a clearly articulated design storm. In the Netherlands, most structures are designed to withstand a 1 in 10,000 year storm, and provision that structures must be upgraded as the threat evolves are common. In the U.S. waterfront structures are typically designed to much lower standards, and perhaps more importantly the standards are not consistent. It is quite common to find bulkheads designed to protect from a 1 in 50 year storm alongside rock revetments designed to the 1 in 100 year standard, with neither having a plan for adaptation for an evolving threat such as sea level rise. The first step in creating more secure and resilient waterfronts is providing guidance to the engineering community in the form of codes that define consistent requirements for waterfront design.

3.2 **Social Capital**

Part of the post-Sandy study findings from the earlier investigations were that not only is physical infrastructure important to resiliency and recovery but also social interactions and relationships (Smythe, 2013; Wakeman and Miller, 2013). For the purposes of this report, the human factors that can create a network of cooperating individuals will be referred to as "social capital". Lessons learned from public and private stakeholders in the port post-Sandy strongly suggest that understanding social capital could assist in more quickly returning the port to full service following future disruptions (Wakeman and Miller, 2013). What are the mechanisms (e.g., collaboration, common culture, and so forth)? How would physical infrastructure and social capital work together to optimize service restoration in network industries following a disruption? Are there new engineering and social science tools for assisting decision-makers and the general public to be more resilient following a significant disruption?

The ability to recover following a disruptive event depends on many factors. However from several post-event studies, it appears that it is the human factors are among the most influential (Carpenter, 2013). As reported by Smythe (2013), the successful restorative effort following Sandy was due, to a large extent, to the local expertise and coordination activities within the port community and the supportive local state and federal agencies. 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).

3.3 **Interdependencies**

During a disruptive event there are often cascading failures among the lifeline sectors, which include power, communications, water/wastewater, and transportation (NRC, 2009). 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 having no clean water to drink. A National Research Council's report, entitled "*Sustainable Critical Infrastructure Systems*" (NRC, 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."

The maritime logistics sector's water-side (e.g., vessels and waterways) and land-side (e.g., terminal and multi-modal transport) activities are supported by physical infrastructure and social capital that are part of the power, communications and transportation network industries. Once Sandy and its associated surge made landfall, there was significant damage to physical infrastructure of all the network industries and to a lesser degree the region's social capital (Python and Wakeman, 2015).

Previously established policies and practices that were utilized during Sandy allowed for the rapid restoration of water-side maritime operations -- led by the U.S. Coast Guard. (Following Hurricane Katrina, the USCG organized a new unit to oversee preparation and recovery activities in their areas of responsibility called the Marine Transportation System-Recovery Unit or MTS-RU). The restoration of land-side operations to full functionality was less effective. The principle breakdowns were cascading failures among the power, communication and transportation sectors. Decisions as to responses had to be balanced between many competing demands at the state and regional levels. For the supply chain, without a clear course of action at the regional level and little political priority, these cascading failures delayed the container terminals' ability to re-open. For example, because of pressing need for power throughout the metropolitan region including hospitals, electric utility companies were drawn in many directions causing delays in their industrial and port responses. It also resulted in intermodal and multimodal cargo movements being delayed for several weeks while they re-organized their business operations (Wakeman and Miller, 2013).

3.4 **Developing Guidelines and Tools**

A new understandings of physical infrastructure and social capital, their relationships and capabilities to enhance resilience of communities and particularly ports and their supply chains is at the center of this investigation. Development of new engineering tools and socio-technical guidelines are a focus and end-game but are not necessary to be successful in expanding our understanding of these issues (Mansouri, Nilchiani *et al.*, 2010; Omer, 2010). The research focused on the principles that worked to allow disrupted operations to be restored to their fully-functioning status. It also attempts to formulate resilience approaches that are practical and ready for implementation in the field. Part of the overall study purpose is to develop guidelines and tools for enhancing resilience in design and engineering practice as well as for developing instructional frameworks. Finally these guidelines and tools developed from lessons learned from prior disasters and are meant to assist in decision-making to reduce the impact of disruptive events in their communities.

New socio-technical guidelines must attempt to incorporate both physical infrastructure and social capital characteristics. Engineering tools (such as risk assessment, adaptive management, sensor technologies, asset management, agent-based models, and whole life cost analyses) should consider the tools' utility for enhancing not only resilience but also fostering greater sustainability. Such methods are often prescriptive and direct participants without providing sufficient flexibility. Methods that focus on outcomes while also allowing emergency personnel to use best professional judgment for any particular event are more adaptive.

Since there is a paucity of tools that can be utilized to construct greater resilience (Bach, Bouchon *et al.*, 2013), this research seeks to incorporate lessons learned from prior disruptions, including Sandy, into a composite set of guidelines to help direct decision makers to prepare and recover when faced with devastating port flooding and system damage due to climate change related events. During earlier work in the Port Of New York and New Jersey (Wakeman and Miller, 2013), Ms. G. Python, then a Master of Science student at Stevens Institute of Technology, began the process of conceptualizing a set of guidelines that could be a foundation for constructing an organization framework in the port environment to promote resilience in the port recovery and supply chain business continuity following a disruptive event (Python, 2013). This research furthers and builds on that earlier work.

4. Resiliency Frameworks

4.1 <u>**Gathering Input**</u>

The review of the literature on resilience, particularly port and supply chain resilience, included related literature on port security and emergency management during major disruptive events. Differences in type and also physical extent of disruptions were examined and key physical, logistical, and institutional (including communication) issues were noted and use to identify potential impacts of maritime sector failures. For example, the characterization of disruptions to part of a large port (e.g. a loss of one terminal among many) versus loss of an entire port's operational activities (e.g., the closure of New York Harbor or the Port of Los Angeles labor event) or the difference between planned disruption (e.g., lock maintenance) and unplanned closure of a waterway (e.g., lock failure) needed to be considered differently (Southworth, Hayes *et al.*, 2014).

In the face of increasingly extreme disruptive events in the urban coastal zone, decision-makers are concerned with the resilience capacity of existing physical infrastructure to natural or human-caused shocks. The National Infrastructure Advisory Council (NIAC), which provides the President of the United States with advice on the security and resilience of the critical infrastructure sectors, found that the resilience of four network infrastructure sectors – energy, communication, transportation, and water – are particularly critical to nation's regions. These four have been designated lifeline sectors by an earlier National Research Council report (NRC, 2009). These infrastructure sectors underpin the key functions of regional government and commerce. In the Council's final report (NIAC, 2013), they provided six recommendations to the President that are repeated in Table 1.

TABLE 1: Key Recommendations to Improve Resilience
(Source: NIAC, 2013)

	Recommendations to the U.S. President - National Infrastructure Advisory Council
1	Form partnerships with senior executives from the lifeline sectors, based on the Federal government's successful executive engagement with the electricity sector.
2	Identify or develop regional, public-private, cross-sector partnerships, led by senior executives, to coordinate lifeline sector resilience efforts within a given region.
3	Designate the energy, communications, water, and transportation sectors as lifeline sectors and direct all agencies to recognize the priority of the lifeline sectors and the individuality of regions.
4	Integrate social media into public alert and warning systems and work with state and local government partners to develop social media information sharing capabilities to inform response.
5	Launch a cross-agency team to develop solutions to site access, waiver, and permit barriers during disaster response.
6	Create a strong value proposition for investment in resilient lifeline infrastructures and accelerate the adoption of innovative technologies in major infrastructure projects.

These are national recommendations that have merit and are foundational. They begin with greater efforts at communication and end with acceleration of innovative technologies. How can they be constructed into implementable practices for communities and specifically the transportation sector?

4.2 **Earlier Findings**

In 2012, the University Transportation Research Center (UTRC), Region 2, supported a study of post-Sandy lessons learned from a variety of stakeholders in the Port of New York and New Jersey (Wakeman and Miller, 2013). These discussions with stakeholders followed quickly, within the first several months after Sandy, and they helped expose the underpinnings of the recovery activities – it was not just the mechanical or structured emergency management systems, but it was also the human systems that counted in maritime system recovery. There were several generalized principles that emerged from the stakeholder interviews; these included considerations from decision makers and practitioners (Wakeman and Miller, 2013). Several executive level leaders that were interviewed during the 2013 study repeatedly stated similar principal lessons. These were:

(1) Safety and protection of life is their prime consideration.
(2) Communications among decision-makers and with staff is critical. Make plans before hand to provide leadership across organizations with strong and redundant communication systems between the leadership entire team and with 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 to be used in an emergency situation.

While most of the waterside structures made it through the storm relatively 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 an extreme high tide. Storms such as Sandy are relatively rare; however sea level rise is known (NRC, 2013), and the likelihood that storms capable of having similar impacts will occur in the future is increasing. Hence, it is prudent to consider potential upgrades to current guidelines and codes for coastal infrastructure.

4.3 **Data Collection**

The supply chain depends on the efficient movement of freight in a multimodal context. In general, however, there is a paucity of multimodal studies on the resilience of transportation infrastructure in this context. An attempt to specifically identify port resiliency principles from the literature had limited success due to the lack of available after-action accounts in seaports (Madhusudan and Ganapathy, 2011). Given what was available from the open literature, particularly the port security literature (Barnes and Oloruntoba, 2005), generalized procedures from the literature were distilled to obtain a conceptual resilience enhancement process. Categorization of activities by time, i.e., before, during and after an event, was the simplest initial breakdown. This approach, which is taken from Department of Homeland Security definitions (NRC, 2010), considers resilience as part of a temporal risk management framework for planning activities that must occur before a disruptive event occurs. A continuum model is present in Table 2 and suggests that what is currently lacking is the front-end or pre-event planning for creating resiliency. Given the work untaken since 9/11, the model suggest that the majority of planning work for response and recovery is complete.

TABLE 2: Risk Management Continuum for Infrastructure Systems*

Pre-Event	***Event or Shock***	***Post-Event***
Resiliency	Response	Recovery
(Planning limited or missing)	(Planning complete)	(Planning complete)
Preparations require months to years	Practically instantaneous or very rapid (hours to days)	Trade resumption, business continuity, etc. can have durations from days to months to years

(*Note: Recovery duration is inversely proportional to completeness or maturity of resiliency planning activities prior to the event, which are assumed to be limited.)

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 institutional policies and mandates and (2) those issues that are characterized by individual or non-institutional group behavior.

4.3a. *National Conference*

The Transportation Research Board (TRB) and the Committee on the Maritime Transportation System (CMTS) organized the 3rd Biennial Research & Development Conference, held on June 24-26, 2014 at the National Academy of Science Building in Washington, D.C. The conference was entitled: Innovative Technologies for a Resilient Marine Transportation System (MTS). It was organized to examine the use of innovative technologies and practices in marine transportation and waterways management (CMTS, 2014). TRB has been active in assisting state transportation agencies in assessing their emergency management and resilience requirements as well as providing guidance regarding areas where resilience capabilities are needed as shown in Table 3.

TABLE 3: Transportation Agency Resilience: Fundamental Capabilities

(Source: Transportation Research Board, 2015)

Prevention	***Protection***	***Mitigation***	***Response***	***Recovery***
Planning				
Public Information and Warning				
Operational Coordination				
Intelligence & Information Sharing	Access Control	Long-Term Vulnerability Reduction	Critical Transportation	Infrastructure Systems
	Physical Protective Measures			
Screening, Search, & Detection		Risk & Disaster Resilience Assessment	Operational Communications	
	Risk Management			
	Supply Chain Integrity & Security	Threat & Hazard Identification	Situational Assessment	
Cybersecurity				
Training and Exercises				

At the TRB-CMTS conference, two sessions dealt with MTS resilience. At the invitation of the organizers, two papers were presented: one paper on the morning of the first day on port resilience (June 24th) and the second was scheduled on the second day (June 25th). Wakeman moderated the second session and gave a paper on the University Transportation Research Center work from 2012-

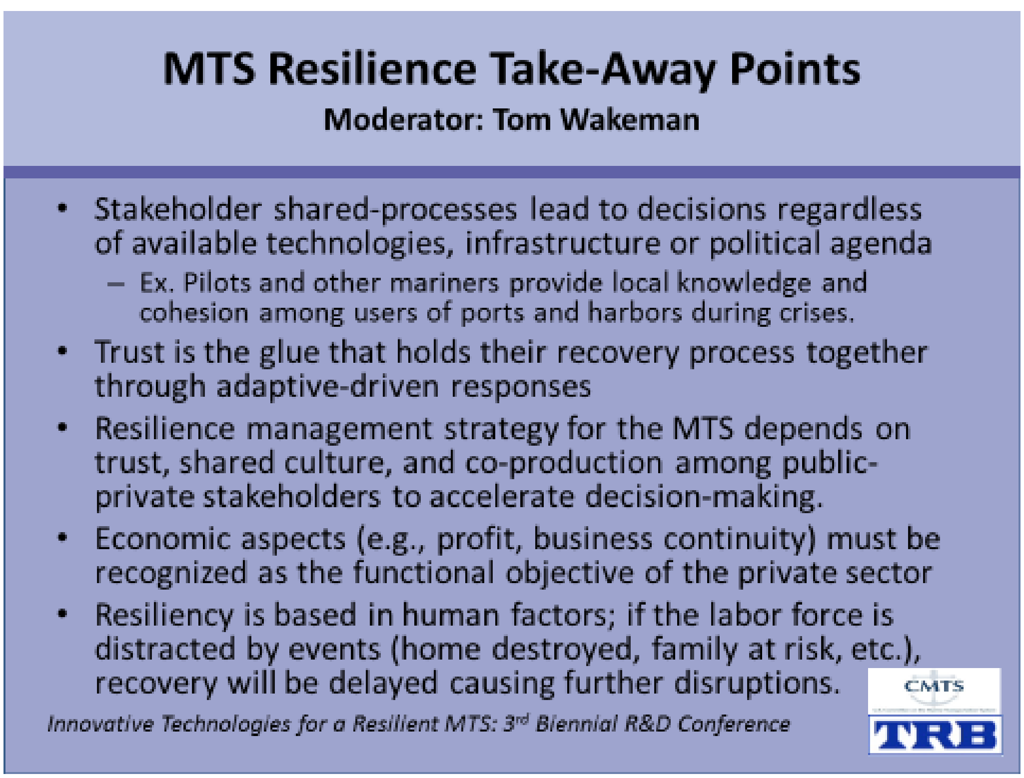
2013 on the lessons learned at the Port of New York and New Jersey post-Sandy. The panel included four speakers with individual papers addressing difference issues regarding resilience (see Table 4).

TABLE 4: Second Session Speakers, Affiliation, and Topic

Speaker	***Affiliation***	***Topic***
Jennifer Wozencraft	USACE Coastal Program Airborne Lidar Bath Tech Ctr	USACE National Coastal Mapping Program
Austin Becker	University of Rhode Island, Dept Marine Affairs & Land Arch	Stakeholder vulnerability assessment of maritime infrastructure Case Study
Thomas Wakeman	Stevens Institute of Technology	Port Resilience and Super Storm Sandy
Jesse Feyen	NOS Office of Coast Survey/Development Laboratory	Preparing for the Storm: NOS Predictions of High and Low Water Levels

The four speakers addressed specific aspects of climate change and particularly focused on technical aspects. Two papers (Becker and Wakeman) also considered community and social influences on resilience. A discussion followed the panel's presentations that included comments from the audience. A summary slide for the resilience sessions was prepared and presented in the closing session. The slide is presented at Figure 1.

FIGURE 1: Summary Slide for TRB-CMTS Resilience Sessions



Many of the points that were raised during the panel's presentations and subsequent discussion were also captured for the closing plenary session held the last day of the TRB-CMTS conference. Several keys points were about resilience and technological enhancements to maritime practices in the MTS sector. Interestingly, although it was a conference that sought technical solutions to resilience achievement, the summary points, which were gathered during the post-panel discussions, primarily addressed issues that dealt with personal stories about human factors and individual contributions to resilience and incident recovery activities following a post-disruptive event.

4.3b. *Regional Workshop*

The TRB-CMTS conference presentations and discussions were used to develop a conceptual framework that includes both physical infrastructure and social capital inputs. It was intended that it would assist in the set-up of the workshop, and where these ideas on resilience will be further explored. The workshop was organized in concert with the DHS Center for Secure Maritime Commerce at Stevens Institute of Technology to further explore the relationship between physical infrastructure and social capital examined during the TRB-CMTS conference. The objective of the workshop was to discuss the resiliency of physical and social assets and to work on documenting activities that strengthen their relationship and increase decision-makers effectiveness during incident response and recovery from natural and human-caused disruptions.

The workshop focused on the urban coastal zone with two expert-led sessions (see the agenda at Appendix A) and included specifically invited participants from both the public and private sectors (see Appendix B). In addition to the experts, approximately 8 students joined the workshop to take notes and learn from the discussions. Figure 2 shows the participants at work during the workshop.

FIGURE 2: Resilience Workshop, November 14, 2014

The morning session consisted of two panel discussions to set the stage for the afternoon session. The first panel included experts on options for physical infrastructure (structural and non-structural) construction in port and urban environments and was titled “Tomorrow’s Coastal Infrastructure Systems”. The panel examined the typical and innovative infrastructure systems to stabilize the urban coastline. It considered the potential role of non-traditional green infrastructure (also frequently referred to as living shorelines, ecologically enhanced shorelines, and natural/nature based features, among other epithets) in enhancing the resilience of urban coastal communities.

The second panel was composed of experts in organizational consistency, collaboration, and business continuity strategies. They discussed the principles necessary for social capital to develop at the community level including the necessary contributions of the private sector.

The objective of the afternoon session was to conceptualize an implementation process that could provide a systematic approach to protection and resilience in the urban coastal environment, particularly with respect to transportation (e.g., port and supply chains sectors). Two facilitated discussions with small groups of about ten people were used to define specific steps and response and recovery activities and to document findings and best practices.

Discussions were organized to have the participants discuss and consider both traditional institutional and public agency-driven approaches and non-traditional private individual and group approaches for enhancing resiliency. The separate discussions focused on how stakeholder qualities are valued within the existing social capital and what incentives are needed to enhance processes. The outcome of the participants’ discussions developed unique lists of options and implementation processes following disruptive events for public and private actors to consider. The principal findings are listed at Table 5.

TABLE 5: List of Final Session Principal Findings

	Resilience Workshop Findings
1	Broader range of communications is needed among the community of stakeholders including types of vulnerabilities, risks to local physical infrastructure and social capital, range of potential civil preparations, and sources of information.
2	Must seek public-private partnerships among stakeholder community, particularly when the private sector has control over assets including finances.
3	Cost sharing will be necessary and should be based on who is the beneficiary.
4	Greater emphasis is need for collaboration among public and private stakeholders and to identify economic and social incentives for private parties to participate in resilience planning.
5	Educational activities should present case studies where communities were engaged and the protocols they develop proved useful and were successfully implemented.
6	Develop constituencies to provide long-term support for elected officials championing resilience and to promote and carry out resiliency plan implementation within their community.

The participants also listed their proposed directions for future research that they felt could be beneficial. These research areas are listed at Table 6.

TABLE 6: List of Proposed Research Areas

	Research Questions Generated during Workshop Discussions
1	How do you identify physical infrastructure and social infrastructure attributes and how can they be monetized in order to quantify the value of investments?
2	How do we develop risk-based metrics?
3	How do you identify best management practices for disruption recovery and business continuity?
4	How could a resiliency framework and index be developed?

5. Formulating a Resiliency Framework

As stated earlier, the objective of this research project is to move the aspirational concept of resilience to a standardized framework, guideline or protocol that is a normative process for creation of resilience in transportation systems, particularly maritime systems. The next section considers both the area of building codes and the area of social networks and suggests methods to integrate the two in a structured fashion that is easily repeatable and specifically tailored for the freight transportation portion of the supply chain.

5.1 <u>**Physical Infrastructure Guidelines**</u>

Once Sandy and its associated surge made landfall, there was widespread damage to maritime terminals and infrastructure throughout the region. The first UTRC study was conducted to identify lessons learned that could assist in returning the port to full service more rapidly (Wakeman and Miller, 2013). The specific objective of that study was to identify guidance that could enhance port resilience. The project reviewed the existing design codes for infrastructure and attempted to identify how building codes could be improved to protect maritime to protect infrastructure integrity. It was found that Sandy had a relatively minimal impact on waterside structures at shoreline including port facilities at container, passenger, and oil terminals. Piers and wharves in large ports are typically designed to withstand horizontal impact loads from fully loaded ships and vertical loads associated with cargo handling equipment. However, there was damage to many facilities and equipment and to passenger cars because of flooding. For example, tanks at petroleum terminals were washed off of their foundations by the storm surge.

While most of the waterside structures made it through the storm mostly unscathed, there were many instances of wave and surge related damage to ancillary port structures. Most of the major damage was related to the inundation associated with the storm surge plus a high tide, which led to water levels in excess of 12 feet above normal tide levels. Hence the 2013 study identified flooding as a key issue to resolve in an effort to enhance resilience. The current study moved from simply examining structural integrity to a broader approach for using building codes and operational activities to enhance supply chain resilience.

5.2 **Building Codes**

Based on a review of existing building codes and the lessons learned port stakeholders during the earlier study, modifications (shown in Table 7) to the currently applied local uniform building codes for the urban waterfront were recommended for consideration (Wakeman and Miller, 2013).

TABLE 7: Recommended Modifications to Port's Building Codes

	Code Recommendations for Port of New York and New Jersey
1	The building codes of the states of New York and New Jersey should be updated to include port specific sections, which are uniform for the entire harbor region.
2	The states should adopt and directly reference the American Society of Civil Engineer's Flood Resistant Design and Construction Standards (ASCE 24-05) for siting of critical utility and mechanical equipment for all port facilities.
3	The Port Authority of New York and New Jersey should add a section to their lease agreements devoted to port specific structural design and construction considerations.
4	All facility owners in the harbor should adopt a reasonable and consistent methodology for incorporating sea level rise into their planned facility upgrades.

As discussed earlier, an expert panel was convened to examine coastal infrastructure systems as a part of the Physical and Social Infrastructure Resilience Workshop. The panel was comprised of representatives from engineering consulting firms, the U.S. Army Corps of Engineers, and local governmental agencies. During the presentations and subsequent discussions, communication at all levels and between all parties was one of the main issues that was emphasized. This included communication between public and private entities with a stake in improving port and community resiliency, as well as communication of the residual risk to private citizens. One of the common themes was that engineering projects designed to enhance infrastructure resiliency and reduce risk typically do not eliminate the risk entirely. Moving forward, the panel felt it was essential to be able to communicate this residual risk, so that informed decisions could be made with regards to future infrastructure investment.

5.3 **Social Capital and Recovery**

The high value and volume of commercial goods moved into and out of the United States on the water make maritime ports indispensable, not only for the economy but also for the citizens that depend on these goods and material resources to maintain their way of life. However, the location and nature of ports make them susceptible to both natural and human-caused disruptions and occasionally disasters. Ports inherently have some level of vulnerability to disruptive events because of their location (adjacent to waterways) and their interdependencies (societal and commercial), but typically the resulting impacts from disruptions can be managed and business continuity maintained including supply chain mobility.

Sandy and other significant weather-related event combined with future trends of sea-level rise and increasing storm severity have demonstrated that reducing the impact of coastal flooding on communities and to the maritime supply chain is an economic imperative. It was evident from the earlier Sandy investigation that many stakeholders felt that one of the keys to their success in reopening the port quickly was their ability to improvise and establish processes that drew on their prior relationships, their shared experiences, and their trust in one another's professional expertise. These relationship stem primarily from existing organization with communication and coordination responsibilities that were either within government, the private sector, or some combination of parties (Southworth, Hayes *et al.*, 2014). There are several regional and state coordinating bodies that are responsible for emergency response and recovery efforts in the New York metropolitan region -- multiple states and within their boundaries. The primary organization on the waterside of the harbor is the Maritime Transportation System-Recovery Unit (MTS-RU). The MTS-RU was established following Hurricane Katrina by the United States Coast Guard. In the wake of a port disruption, the MTS-RU is responsible for coordinating the recovery of the affected port and its waterways.

As reported in the post-Sandy interviews, the port partners' relationships were defined as having shared values (Smythe, 2013). Because of their shared values and institutional framework the MTS-RU was able to provide each other mutual access to information and resources. It is these relationships within the MTS-RU that encouraged action in the face of uncertainty. Additionally, the community spirit demonstrated by the MTS-RU seemed to create a magnetic attract to others that also volunteered their assistance to the cause of port recovery. This shared spirit of community responsibility spread. Interviewees reported that their collaborations and shared commitment seemed to spawn outside interest, resource contributions, and personal time contributions by third-parties (Wakeman and Miller, 2013).

The maritime logistics sector's water-side (e.g., vessels and waterways) and land-side (e.g., terminal and multi-modal transport) activities are supported by physical and social assets. Once Sandy and associated surge made landfall, there was significant damage to physical infrastructure and to a lesser degree social capital. Current policies and practices were successful in restoring water-side marine operations, led by the Coast Guard through the MTS-RU; restoration of land-side operations are less successful. The principal breakdowns were cascading failures among the power, communication and transportation sectors. For the supply chain, without a clear course of action on the landside, terminals were able to open and intermodal and multimodal cargo movements were delayed for several weeks. Hence, a proposed land-side organizational guideline to aid decision making to reduce the impact of flood events was developed using lessons learned during the post-Sandy interview (Python, 2013) and this study.

6. Integrated Framework/Guidelines

Transportation security demands a role for resilience. Measures to evaluate the potential resilience of a transportation system can be based on the vulnerability, flexibility, and resource availability to cope with a terrorist attack or natural disaster (Cox, Prager *et al.*, 2011). Is it possible using such metric in a universal manner to formulate an integrate framework that is comprehensive in its treatment of the physical and social assets for ports, which supports both the community and operational environment of the supply chain? What are the components of this framework, guideline or protocol?

For United States' ports, the waterside of the supply chain has a hierarchical organization in the USCG's MTS-RU to lead and support resilience activities primarily on the waterways and terminal quays. On the landside, there is not similar command structure or organizational corollary. During Sandy, although the Port Authority of New York and New Jersey's incident management team worked hard to coordinate terminal elements, the transportation components often acted unilaterally. In her Masters' thesis, based on research conducted during the 2013 study, Python (2013) proposed a new organizational structure to help facilitate the recovery of terminals and intermodal connections, and to address flood mitigation and service restoration. The organizational guidelines describe possible approaches and methods for restoring normal port supply chain operations through collaborative principles by establishing a land-based logistics team that includes all multimodal connectors (Python, 2013).

The US Coast Guard opened the port to maritime activity after about a week -- but the landside continued to be crippled and provided only partial transport and other logistical services. There was a limited coordination for landside activities -- mainly provided by individuals at the Port Authority of New York and New Jersey (Southworth, Hayes *et al.*, 2014). Otherwise there was little on the off terminal activities that directly corresponded to the effectiveness of the MTS-RU's collaborative activities on the waterside. What was missing was the same organizing principles that were working for the MTS-RU 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 to be cut-off from other network industry sectors (including power) and their recovery activities by political priorities. In fact State and New York City government emergency operations did not seem to view the port and the supply chain as a whole – 186 facilities – nor recognized their essential contributions to the region's recovery.

If ports throughout the country were to use a similar organizational standard and implement the recommended cooperative practices initially presented by Python, they could assist one another during periods of distress. The routine application of standard practices could help create more resilient ports and logistic practices, and enhance regional and national economic resilience by increasing redundancy. Clearly, the relevance of transportation, social capital and other decision influencing factors in the achievement of system resilience deserves considerably more attention from academia and the public sector.

6.1 **Universal vs. Unique**

Regarding the question of creating a universal resilience framework for all ports, this is only possible if all ports and their surrounding urban communities are somewhat uniform. Reviewing the annual report of the American Association of Port Authorities (AAPA, 2015) demonstrates the wide differences between ports from difference regions of the country. The public interests in a limited area of the country is often uniform with respect to public infrastructure like ports; furthermore, their communities are typically uniform. An example are the Ports of Los Angeles and Long Beach have many characteristics that they share so that a framework that works for one should be able to work for both. The Port of Houston in Texas and the Port of New York and New Jersey, on the other hand, are significantly different in their cargos, their layouts and their services – a common framework would probably not work if too detailed or prescriptive.

Not only ports but also every coastal community has its own personality. Citizens can be from the same region but have significantly different values and desires and demand to control their individual destiny political and social. For example, the restoration of the Jersey shore post-

Sandy demonstrates this home rule philosophy (Gurian, 2013). Each community along the shore wants to dictate their own response to the call for greater shoreline protection – some want berms, others seawalls, others boardwalks and others nothing blocking their view of the ocean.

Home rule also applies to ports. There is a common saying among maritime folks: “When you have seen a port, you have seen a port.” The idea behind this saying is that each and every port is unique because of the enormous diversity and variety of parameters involved in characterizing a port – everything from the types of cargo to the types of governmental oversight. With such a broad spectrum, is a uniform protocol for communities and ports achievable? In fact, is it possible with their competitive attitudes, is it even desired by this fiercely independent parties? This section attempts to tackle describing physical infrastructure and social capital resilience separately but seeks to integrate them, looking for a nominal resilience framework/guidelines.

6.2 **Evolving Physical Standards**

On the physical infrastructure side, a more resilient coastline can be achieved through the adoption of consistent, coordinated, and forward thinking building codes that reflect the most recent state of the science. Wakeman and Miller (2013) reviewed the impacts of Hurricane Sandy on the Port of New York and New Jersey and identified several lessons that in the context of the present work help define a path forward. Two of the messages from that earlier work were the need for consistent design guidance on the coastal engineering aspects of facility design and the adoption of regionally consistent and conservative design flood elevations. Two challenges that were identified in implementing these measures in an urban setting were the uncertainty of future conditions and the need for maintaining service/use while in the process of adapting. Of course the elephant in the room, is finances. Who pays? Especially once federally funded storm relief programs end.

A related issue is the need for regionally consistent and conservative design flood elevations. The current system is inadequate in that it is based on static Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMS), which are developed in support of the National Flood Insurance Program (NFIP). The NFIP is tasked with reducing the impact of flooding on public and private structures by providing affordable insurance to property owners and encouraging communities to adopt and enforce sound, risk-based floodplain management regulations (FEMA, 2015). Risk is established through a technical process that uses detailed modeling to establish the areas at risk from storm surge and wave attack. In coastal areas, zones (designated as A, Coastal A, and V) are used to delineate areas of low (<1.5 feet), moderate (1.5-3.0 feet), and high (>3.0 feet) wave activity (FEMA, 2005). Building code requirements are typically linked to the zone designation identified on the FIRM. An issue identified by Wakeman and Miller (2013), is that because of their size, ports often span one or more flood zones, which can result in the application of different design standards within the same port facility. It was recommended that states, communities, and port authorities adopting a consistent standard across zones and jurisdictional boundaries within a port region.

As mentioned earlier and brought up during the Resilience Workshop is that the flood zone delineations are static and do not take into account the impact of sea level rise. As such they establish a baseline threat that does not increase within real-time. Revising the baseline must wait until the maps are updated, sometimes decades later. Many communities use freeboard requirements as a way of overcoming these shortcomings, but the prevalence of home rule in many places results in neighboring communities with widely varying design elevations.

Wave resistant design is a consideration that is rarely addressed at the community level. The Federal Emergency Management Agency's flood maps define the areas in which more rigorous wave resistant design and construction practices must be used (V-zones). However this line is also static and based on the understanding of the threat at the time the maps were created. While most local building codes adopt more stringent standards in these wave impacted areas, they generally do not include any means of adapting to the threat as it evolves. An approach that has gained traction in New Jersey since Hurricane Sandy is the official adoption of more stringent design and construction standards for Coastal A zones (FEMA, 2005;Mikle, 2015).

One of the challenges to adopting more stringent design standards is the general uncertainty surrounding future conditions. On a philosophical level, most rational people agree that conditions are changing and it makes sense to adapt; however for the people responsible for investing in adaptation measures, the concept of change is often not enough to justify the significant expenditures required. This is even truer in an economic climate where there is often intense competition for a shrinking amount of financial resources. Another challenge identified during the workshop relates to the difficulty of undertaking measures to enhance resiliency in urban settings without significant disruptions to the community. This problem is particularly true of climate change's long term impacts. Perhaps in the short term, the clearest example is the common flood hazard mitigation response of elevating vulnerable structures. In urban residential settings, where row houses are common, or in industrial port settings where operational constraints are an issue, the standard approach of elevating structures is more difficult to apply.

One of the clearest messages that came out of the coastal resilience workshop was the need for incentive programs, which most likely will have to rely on public private partnerships. In order to enhance structural resilience the first step will be defining "the standard". Once the standard is agreed upon incentives can be defined based on achieving and/or exceeding the standard. The example identified during the resilience workshop was the Community Ratings System (CRS), which provides reduced flood insurance premiums for communities which take steps to reduce their flood risk (FEMA, 2015). A similar or expanded program which offers incentives for undertaking resilient design practices that goes above and beyond what the CRS offers and is more applicable to urban environments would be one possible framework.

6.3 **Emerging Social Assets**

Building social capital has been accomplished where there are existing social networks, and when there is sense of belonging to a stakeholder group (NRC, 2011). Typically it is achievable when there are public-private partnerships between parties that share common values and have a clear mandate to stabilize their actions (International and Corporation, 2014). Supply chain disruptions have demonstrated that there is potentially a limiting factor in a port's resilience capacity; it is the coordination of waterway activities with the terminal side activities including the land side operations and intermodal connections (Wakeman and Miller, 2013). A key result of this finding involves the suggestion for port regions to form a land-based logistics team to enhance coordination (Python and Wakeman, 2015). In order to fill the communication gaps of the current system, a new or enhance organization is needed to bridge the observed disconnect in the supply chain between the waterside and the landside operations. It is recommended that an independent landside team be organized to strengthen terminal and intermodal connector communications if local service provider associations are present -- as in some ports -- and in ports without such service provider associations, should be created. These teams become the social groups that will create social capital with the surrounding communities to enhance resilience if there is a supply chain disruption – separate from the activities of the MTS-RU in the harbor.

Beyond the establishment of a landside logistics team, the port region must establish a tiered decision making structure and guidelines for policies and pre- and post-disruption activities. Python (2013) listed pre-event activities to prepare for port disruptions from flooding. She identified a series of specific actions that should be undertaken, and then organized these into a standardized framework that depends on the collaboration of four organizations. The first tier of decision making is focused in two coordinating bodies: a regional coordinating body and a state coordinating body. This tier works with federal coordinating units. In addition, there is a second tier that is primarily concerned with on-the-ground activities during and following the disruption. In the port area, these coordinating bodies would be responsible for the recovery of the waterside and landside transportation activities respectively. Figure 3 shows the relationships of these proposed coordinating bodies and teams.

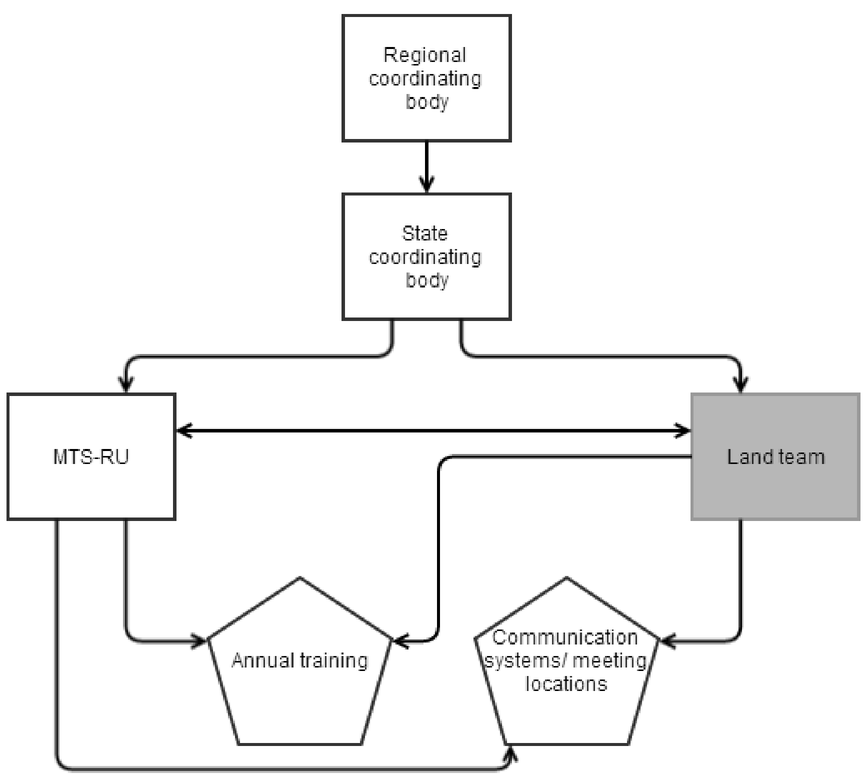


FIGURE 3: Coordinating Bodies and Joint Efforts

For example in the Port of New York and New Jersey, the regional coordinating body could be the Port Authority's Emergency Management Office (OEM) and the OEM of the states of New York and New Jersey could be the state level organizations. The local coordinating bodies in the port domain are the MTS-RU (waterside team) and a landside logistics team (still to be formed). There would be joint efforts among the organizations to enhance communication and collaboration by holding training sessions and working to enhance shared emergency communication systems and meeting locations. Other regions could have a different arrangement as long as the four main coordinating bodies are represented.

This suggested organizational framework is consistent with the findings and recommendations from the National Infrastructure Advisory Council (Section 4.1), the prior post-Sandy interviews (Section 4.2), the National TRB-CMTS Washington D.C. conference (Section 4.3a), and the November Resiliency Workshop (section 4.3b). All of these sources point to a need for greater collaboration among impacted stakeholders. Collaboration among supply chain players over the last year in combating congestions at the nations' ports has demonstrated that cooperation among multiple business adversaries is possible (Kulisch, 2015). An effort to share information and best practices among members of the supply chain resulted in the breaking the gridlock that had plagued the container traffic on both coasts. This same high degree of cooperation and collaboration is needed for supply chain resiliency enhancement during disruptions.

7. Supply Chain Collaboration

When a disruption occurs to the supply chain, there are rapidly spreading business consequences that go beyond the impacted region. Establishing cooperative relationships among ports provides redundancy. The first concern is to ensure that the flow of goods continues as close to normal as possible, which may require goods to be rerouted for a certain amount of time. Of course, port authorities and other governmental agencies do not dictate the routes that cargo flows – that is the responsibility and prerogative of the cargo owner. However, development of cooperative relationships are important steps to enhancing resilience as discussed by the participants in the previously described TRB-CMTS Conference and Resilience Workshop.

Python (2013) also proposed other measures to enhance current port resilience. These additional actions are broken into four over-arching guidelines: contingency port, partnership port, contingency plans, and pre-storm preparations. The relationships among these components are displayed in Figure 4. *Contingency Ports* are ports in the same region of the country that will be able to handle an over flow of goods from a disrupted port. Identifying contingency ports, and providing them with relevant data when disruptions occur, allows for all ports to be aware and prepared to aid each other. Another concern is getting the damaged port back to full functionality. Ideally each port is able to get their own port fully functional on their own. What happens, however, when key personnel are unable to complete their duties following a disruption? Having redundancy for key personnel is necessary. Identifying a *Partnership Port* could allow ports to share personnel in the event of disruption that results in key personnel being unable to complete their job. *Contingency Plans* provide port personnel common knowledge of equipment, where emergency equipment not used during normal operations comes from, and locations or methods for housing personnel, equipment and vehicles to be pressed into service during an emergency.

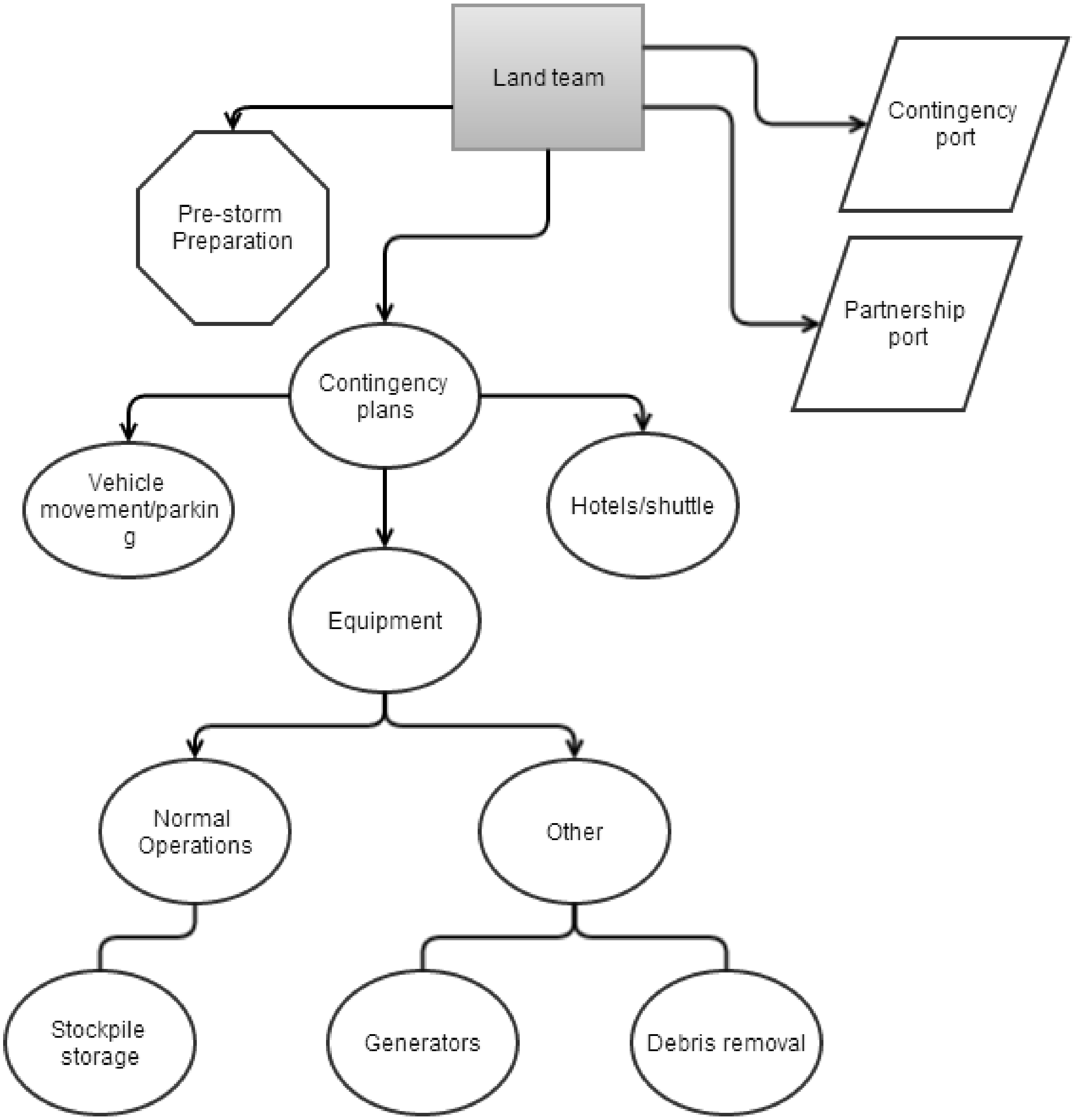


FIGURE 4: Flowchart Depicting Requirements of Proposed Land-based Team

Protecting personnel following a disruption is a top concern for the port (Southworth, Hayes, *et al.*, 2014; Python and Wakeman, 2015). By creating plans for hotel rooms, key personnel, and their families when necessary, can be housed and remain safe throughout the course of the disruption. Such assistance could allow personnel to be free of worry about their families and therefore be able to work more effectively.

Similarly, *Pre-storm Preparations* are important for equipment and supplies. Protection of vehicles helps to ensure that mobile security measures and intermodal connections remain functional and can be used as soon as the port is again operational. These vehicles would require an off-site high elevation location that is removed from the impacts of potential flooding or debris damage. When a location has been selected and is approved for use prior to and during a disruption, the parking area can also be used to ensure that stockpiled equipment remains safe and useable.

As a physical consideration, rather than continuing to stockpile normal operations equipment on the first floor of port buildings, where they are susceptible to the same damage as the equipment that is currently in use at ground level, other storage options should be considered. Retrofitting an empty TEU (twenty-foot equivalent unit) container could serve as a storage location for equipment. During normal operations the storage TEUs could be stacked like other TEUs, reducing the space required, but during a disruption could be picked up and moved to the same parking area as the vehicles.

The storage of equipment used during normal operations provides only one aspect of the equipment used during a disruption. The other aspect is to gain an understanding of how and where emergency equipment, not used during normal operations, will arrive at the port for use in the event of a disruption. Understanding aspects of normal equipment and emergency equipment usage is necessary for effective use in the wake of a disruption.

Taken together, the organizational addition of the landside logistics team and the additional guidelines including contingency port, partnership port, contingency plans, and pre-storm preparations make-up a suggested framework for enhancing port resilience. Figure 5 presents an aggregation of the framework and guideline components described previously and presented in Figures 3 and 4.

8. Findings

This project sought to identify the best developmental practices and interdisciplinary linkages of physical infrastructure and social capital assets to provide for rapid recovery in the coastal zone from the consequences of climate change or extreme events. It sought to answer: How can complimentary physical infrastructure and social capital best be created? How should the construction of these two types of infrastructures be formulated to gain support of waterfront businesses and the acceptance of their neighboring communities? Findings from literature reviews, federal/state agency and industry stakeholder interviews, national and regional meetings as well as analyses of past disruptive events were utilized to describe coastal vulnerabilities, resiliency gaps, and resiliency challenges. A conceptual framework/guideline has been developed to describe building codes and collaborative guidelines for linking waterside supply chain activities and organizing new independent land-based logistics teams with recommendations for their activities to enhance supply chain resilience.

The marine supply chain includes waterside and landside logistics players. The landside logistics team would consist of, among others, specific port authority personnel, customs and border protection, terminal operators, labor unions, truck and freight train operators and distribution centers and warehouse operators. The land team could be its own coordinating body, or a subsidiary of the MTS-RU, but it must create a seamless business connection between these

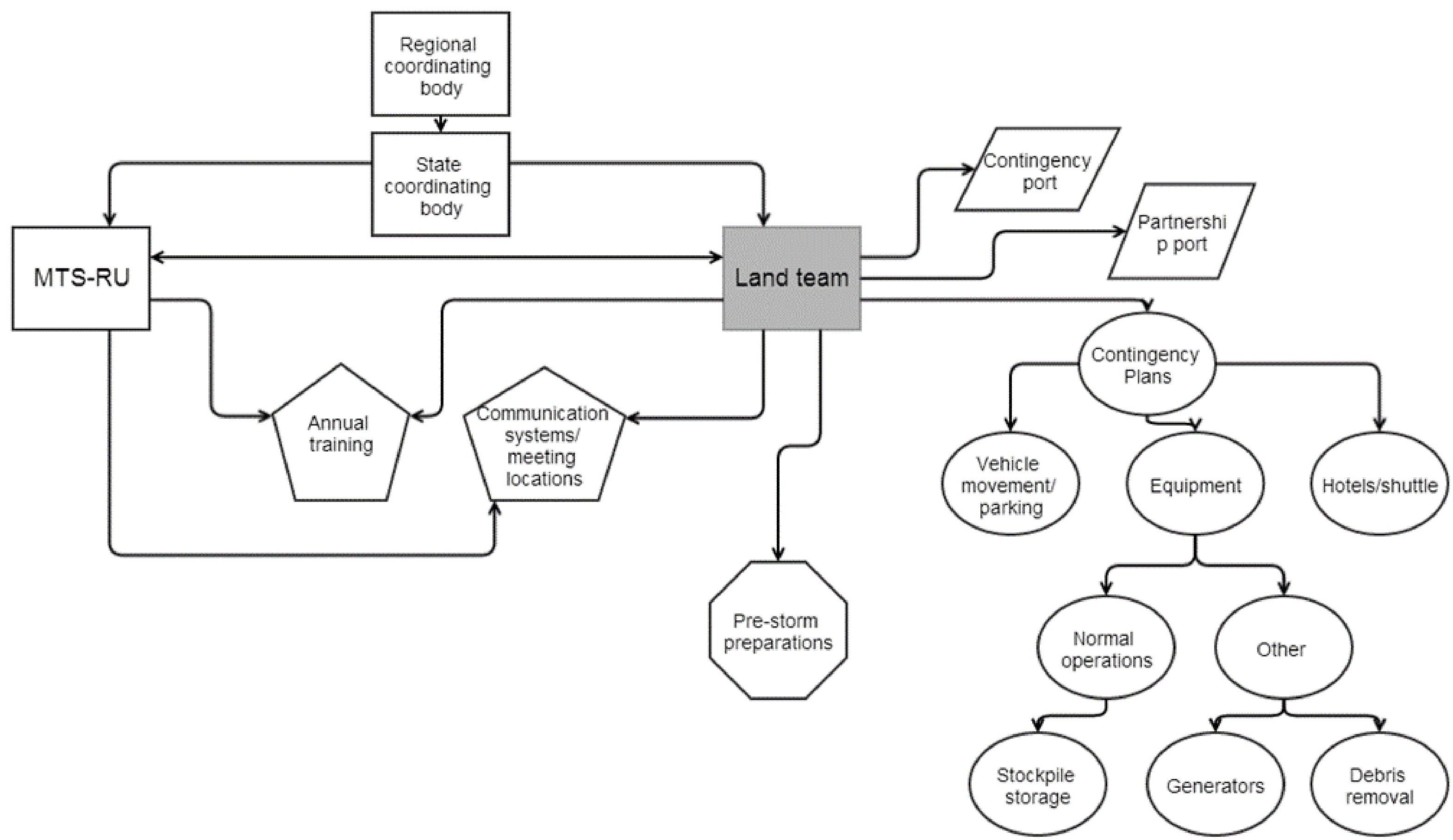


FIGURE 5: Flowchart Depicting Regional Bodies and Actions of Land-based Team

two bodies. The land-based team would be responsible for handling resilience measures for land side operations including loading and unloading of cargo, security measures, and intermodal connections as well as interfacing with the local MTS-RU. Both the MTS-RU and the land team must work closely with each other to help improve port performance and resilience. Effective communication and current training are necessary for every member to perform their jobs properly in a coordinated effort.

These resiliency processes and approaches proposed may be used to reduce consequences of sea level rise and coastal flooding or other disruptions at ports and coastal communities. However, the uniqueness of each coastal community and seaport limits the uniform application of the proposed framework and guidelines because it seems that of the non-uniform characteristics of each situation and the involved community as well as their port facilities inhibits cooperation. (However this assumption has not been tested.) Decision makers will implement plans according to their own needs, policies, and resources. Hence the project developed separate guidelines for the physical infrastructure (i.e., building codes) and another set of guidelines for social capital enhancement (i.e., the land-based logistics team development).

Questions still remain: What are the principles that allow disrupted environments and coastal communities to recover? How can physical and social asset best be used to hasten both environmental and community resources to recover? How can planning be used to avoid cascading system failures? How can we use findings from prior storms to formulate lessons learned that will assist in decision-making to reduce the impact of future disruptive events? New socio-technical guidelines are needed that will attempt to incorporate empirical-based protocols for both physical infrastructure and social capital development in coastal areas.

Finally development is still wanting for an integrated framework and tools for enhancing resilience in design and engineering practice as well as for developing instructional frameworks and practitioner's toolbox for interdisciplinary education.

9. Conclusions

There are growing concerns that a new period of rapid climate change is emerging with anticipated sea level rise. Increasingly the coastal environment is being modified by the built environment including ports, residential areas, and shoreline facilities – particularly as the urban density increases along the shoreline. Guaranteeing the sustainability of the coastal zone built environment and the maintenance of commercial services requires an understanding of local human populations and their behaviors, the adequacy of protective infrastructure, the impact of these on the coastal urban environment, and the decision-making processes that will govern in stressed situations.

Ports are critical element in the global supply chain and any disruption in that transportation system can have significant impacts on the U.S. economy. Climate change and associated sea level rise have the potential to cause significant and frequent damage to the coastal environment if precautions are not taken. The location and nature of a port makes it susceptible to both natural and human-made disasters. Ports will inherently have some level of vulnerability to disruptions because of their location (adjacent to waterways) and their interdependencies (industrial and societal) with their associated communities. Sandy and other recent storms on the Eastern seaboard, combined with trends of sea-level rise and storm severity, have demonstrated that reducing the impact of port damages and community disruptions is an economic necessity. Maritime commerce and ports must have business continuity plans. Actions that can be taken in coastal communities and along the working waterfront that need to include installation of protective physical infrastructure (structural and non-structural) as well as establishment of social capital that will increase resilience.

The primary objective of this research was to make port facilities and associated supply chain transportation operations, and more broadly coastal community facilities, more resilient in the future when impacted by significant storm events like Sandy. It was hoped that if the findings for ports are homogenous across all ports, then their application would also have applicability to other forms of disruptions including terrorism and labor disputes.

A conceptual organizational framework and general operational guidelines were presented to aid and enhance resilient processes, including decision making tiers, were developed to promote better linkages among the waterside and landside component of the supply chain. The guidelines include the establishment of a land-based logistics team to help coordinate and facilitate the recovery of the supply chain components: intermodal connections, warehousing and distribution center activities. Further the guidelines were proposed to ensure understanding of actions that are necessary to respond to flooding, disaster impacts, and system failures across all sectors and supply chain personnel. If ports throughout the country use the same basic guidelines and work to overcome the normal competitive nature associated with the maritime industry, it is proposed that guidelines would allow ports to come to each other's aid in the event of a disruption. This helps create a more resilient port system, further enhancing regional and national resilience.

An overriding focus for this project has been to create uniform multi-disciplinary methodologies that will enable engineers, social scientists and decision-makers to create resilient physical/social assets in coastal environments using a nominative template. The uniqueness of ports and supply chains seems to obstruct application of one formulation for all marine facilities in ports and regional supply chain resilience. The application of this research indicates that coastal communities, and particularly their port facilities, waterfront industries, and associated supply chain transportation operations, will have to individually formulate their unique local circumstances to achieve s more resilient infrastructure to enable both physical and social characteristics to bounce back from disruptions resulting from climate change or other causes.

The one theme that was repeated from expert panels to practitioner interviews was that there must be a communication plan for all stakeholders during and after a disruptive event in order for decision makers to function and for recovery activities to proceed. This is an essential asset that opens the possibilities for communities, ports, and supply chains to be resilient and rebound from disruptive events.

10. Research Recommendations

In summary, there remain several major gaps in the research on the pairing of physical infrastructure and social capital influence on resilience in the coastal zone. It is hoped that any future research on these areas including port assets will garner increased consideration of social science implications for successful integration of physical and social measures.

New interdisciplinary research is needed to understand how social capital and other human factors play into enhancing resilience in the maritime sector and other supply chain systems, to siting of coastal protective infrastructures and the influence of home-rule attitudes, and to gauge community support, particularly with respect to marine transportation systems investments in resiliency given their mix of public and private stakeholders and community concerns.

It would be useful to survey coastal seaports and/or supply chain businesses to determine what activities they have undertaken to enhance resilience. It would be particularly valuable to seek situations where this framework or something similar has been implemented and sub-sequentially a disruption has occurred. The results could be examined to test the validity of the conceptual organizational and operational guidelines presented in this study. Alternatively a group stakeholder could be convened to vet the suggested protocols.

Finally, the results of this study indicate that work is needed particularly with respect to two issues: 1) the enhancement of social capital and social networks in contributing to community resilience and 2) the tendency for network industries to experience cascading failures of services when stressed.

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Appendix A

Physical and Social Infrastructure Resiliency Workshop Agenda

Date: Friday, November 14, 2014

Time: 9:30am to 2:30pm

Location: Stevens Institute of Technology

Babbio Center, 6th Floor, Room 607, 525 River Street, Hoboken, NJ 07030

Workshop Objective: *The objective of the workshop is to discuss the resiliency of physical and social infrastructure and to work on documenting activities that strengthen their relationship and increase decision-makers effectiveness during incident response and recovery from natural and human-caused disruptions.*

AGENDA

Time	Topic	Presenter
09:30	Introductions & Workshop Overview	Wakeman & Miller
10:00	Panel One – *Tomorrow's Coastal Infrastructure Systems*	Miller
	Speakers: John Headland (Headland & Associates); Roy Messaros (USACE); Greg Biesiadecki (Langan); Michael Marrella *(invited)* (NYC Planning)	
11:00	Panel Two – *Decision-making during Periods of Crisis*	Wakeman
	Speakers: Joseph Picciano (NJ OHS&P); Naomi Fraenkel (USACE NAD); Vicky Cross Kelly (Parsons Brinkerhoff); Roland Lewis (Waterfront Alliance)	
12:00	Working Lunch – *Getting Past Individual Fixes to Systematic Adaption*	
12:30	Work Group Discussions a. Moderator A – William Rousse (Alexander Crombie Humphreys Professor, School of Systems & Enterprises, Stevens Institute of Technology) b. Moderator B – Alex Washburn (Industry Professor for Design, School of Systems & Enterprises, Stevens Institute of Technology)	
13:30	Work Group Report-outs by Moderators	
14:00	Recap and Next Steps	Miller & Wakeman
14:30	Adjourn	

Appendix B

Physical and Social Infrastructure Resiliency Workshop
November 14, 12014

Participants List

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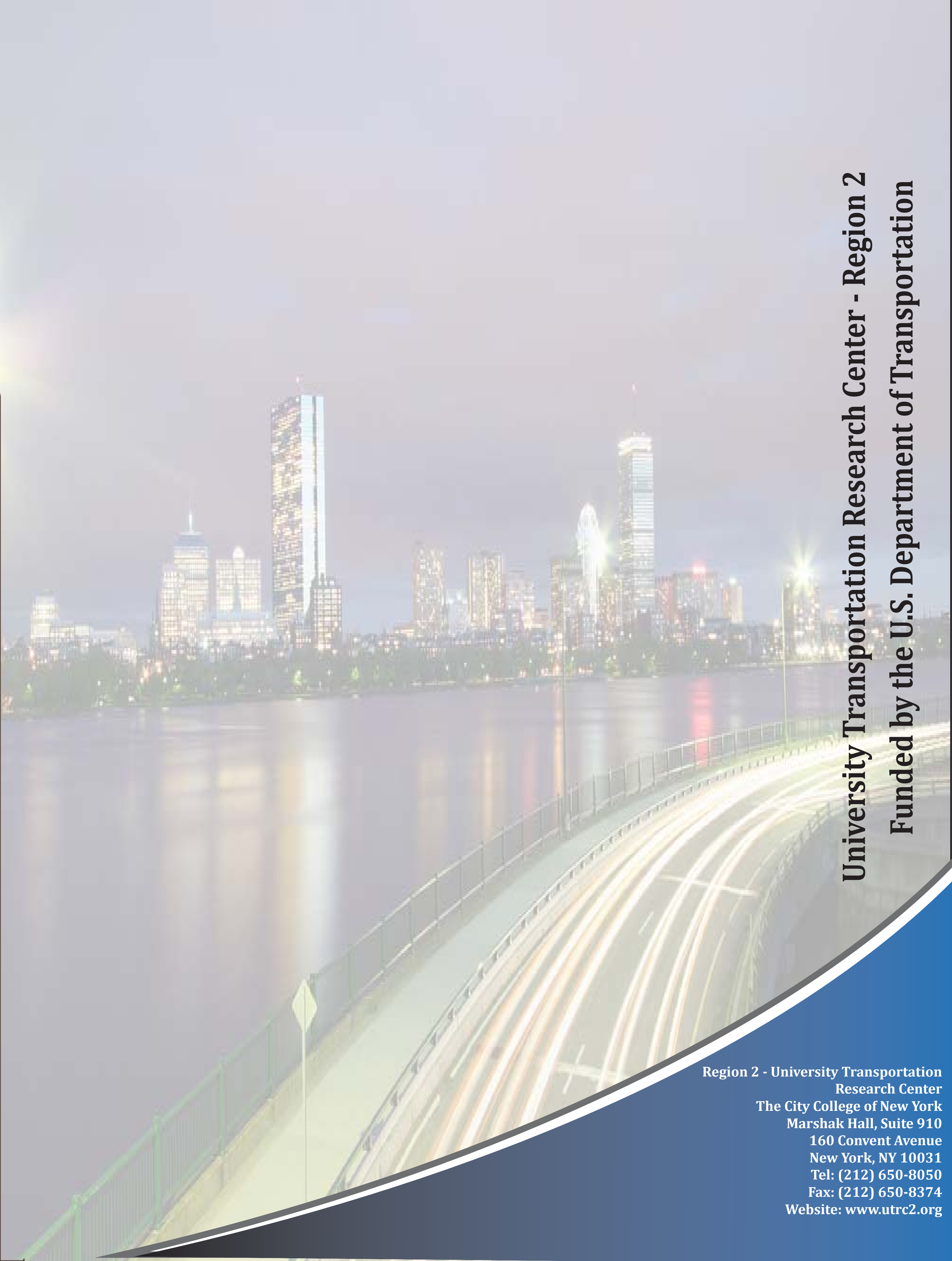

University Transportation Research Center - Region 2

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