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Executive Summary

The thirty-day period from January 24 through February 22, 2015 produced record breaking freezing temperatures and snowfall across the metro Boston region. During that time, 94.4 inches of snow fell on the streets of Boston. Half of the total snowfall (48 inches) came as the result of two storm systems which pummeled the Boston area in close succession: Winter Storm Juno from January 26 to 28 and Winter Storm Marcus February 7 to 10. These two storms individually ranked six and seven amongst the top ten largest snow storms in Boston's history. In all, the period saw a total of five distinct storm systems and multiple days of measurable snow. The total winter snow accumulation was an astounding 108.6 inches, a crippling amount for a densely populated urban coastal city. Numerous longstanding records were broken for snow depth, accumulation rate, consecutive days of snowfall, and consecutive days of sub-20° F temperatures.

The region’s mass transit system bore the brunt of winter’s brute force. During the 30-day period of most intense winter conditions, the Massachusetts Bay Transportation Authority (MBTA) experienced an unprecedented system-wide shutdown of all operations on three occasions, leaving large sections of the metropolitan area immobilized. Official reports relate that on a normal workday, of the 3.3 million people in the Boston metro area, 1.3 million riders use the MBTA to carry out their normal daily activities. Of those riders, 25 percent do not have access to a vehicle for personal transportation and rely solely on MBTA for transit needs. Because commuter trains, the subway system, trolleys and buses are so deeply interwoven into the fabric of the region’s daily activity, the disruption of this sector played havoc on the lives of those who depended on it. This was especially the case for the city’s most vulnerable residents. Overall, the commercial life of the metro Boston region was severely compromised for several weeks. Health care services were also impaired largely due to transport limitations that prevented medical personnel, support staff and the patients themselves from reaching provider locations. In the end, the impacts of the snow storms on the metro-region’s interdependent infrastructure sectors resulted in an estimated $2 billion loss in revenue and productivity, and $393 million in direct costs.

The paralyzing chain of snowstorms in 2015 and their compounding and cascading impacts unfolded over a four-week period. This extended timeframe stands in stark contrast to the dramatic burst of destruction typically associated with earthquakes, tornados, and hurricanes. While the net disruption of people’s lives, the city’s infrastructure, and the region’s economy are comparable to those experienced by catastrophic disasters that have a clear start and finish, emergency plans are generally not set up for managing meteorological disasters that unfold over several weeks. Given that climate change is likely to lead to more of these kinds of extended extreme weather events for metro-regions across the United States, Boston’s experience of dealing with the 2015 snowstorms offer instructive lessons.

This report outlines these lessons and provides concrete recommendations that can help similarly situated communities better prepare for and manage disasters that cause cascading failures to lifeline infrastructure sectors. Its primary audience are decision makers involved with urban planning and emergency management at the metro regional scale. Additionally, there are
findings that should inform federal government leaders who are involved directly or indirectly in advancing infrastructure resilience. Key themes found in the report’s findings and recommendations include:

- **Disasters that unfold over an extended period of time provide special challenges that require recalibrated federal and state disaster laws, regulations and processes, which are currently designed for managing extreme events of a short duration.**

- **Decision makers need routine access to better tools – such as models, simulations, and visualization applications – that empower them with a more robust understanding of the interdependencies and status of critical systems. These tools should also help to guide the most effective sequence of actions to support mitigation, response, recovery, and adaptation. Developing these tools requires access to more comprehensive data that is dependent upon greater public-private information sharing across infrastructure sectors.**

- **Metro areas would benefit from a dedicated regional disaster recovery and restoration planning process that, prior to a disaster, maps out the infrastructure systems that underpin critical functions (e.g. electricity, transport, healthcare, communications, water supply and wastewater treatment) and prioritizes the measures that will facilitate their most efficient recovery. Plans that address the immediate response to individual systems or infrastructure sectors are vital but are not adequate. Instead, metro areas must have recovery plans that account for the complex interdependencies amongst infrastructure sectors to guide the allocation of limited post-disaster resources.**

- **Metro regions typically have economically vulnerable neighborhoods whose residents are heavily reliant on public transportation to sustain their daily lives. These neighborhoods also often house the indispensable blue-collar workforce that is needed in the aftermath of disasters to help make repairs and provide the basic services that are critical to restoring the commercial life of the region. However, post-disaster restoration plans that focus primarily on restoring core city functions often overlook the need to also prioritize restoring services to these vulnerable communities.**

- **A metro region’s social capital is a critical element of recovery and should be enhanced through ongoing community-focused programs and activities. Communities are made more resilient through preexisting civil connections: between citizens and the government; between government and the private sector, and amongst the various social groups within a society. Activities that promote communication across the community and build trust and a common understanding of a community’s strengths and challenges creates the atmosphere in which, following a disaster, crisis situations can be addressed quickly and effectively.**

- **There is a growing need for major investments in maintaining and upgrading legacy infrastructure, and constructing new infrastructures that support functions that are critical to the social and commercial lives of major metro regions. The devastation associated with major disasters is often directly correlated with the age and neglect of the built environment upon which a community depends. The forecasted increased frequency and intensity of disasters reinforces the need to make investment in infrastructure an urgent national priority.**
Incident Description

Winter 2014-2015 started rather quietly in the City of Boston. The region had barely received a coating of snow before the New Year and it was only the eleventh time since recording began in 1920 that December received a total of less than half an inch of snow. The start of winter was also Boston’s sixth warmest in the past 100 years, so what little snow there was quickly melted. In a New Year’s Eve blog, Boston meteorologist David Epstein had lamented that December was a “disappointing month” and that “for some, this isn’t winter.” However, as a “disappointing month” of little snowfall came to a close, it turned out that a record-breaking month of storm after storm was in the offing.

A Record-Breaking Winter

Thirty days in 2015 saw a total of four distinct storm systems and multiple days of measurable snow. The combination of brutally cold temperatures along with record snowfalls created one of the most disruptive sets of winter conditions experienced by the Boston Metro Region in history.

Numerous longstanding records were broken:

- Record snow depth of 37 inches on February 9 (previous record, 31 inches on January 11, 1996);
- Fastest 72-inch snowfall: January 24 to February 10, 2015 (73 inches in 45 days, December 29, 1993 to February 11, 1994)
- Fastest 90-inch snowfall: January 24 to February 15, 2015 (previous record 78 days December 30, 1993 to March 1993);
- Record consecutive days of measurable snowfall: February 7 through 12 (previous record of 5 consecutive days in 1943);
- Most days of measurable snows in a month: 16 in February (previous record, 14 days in March 1916, January 1923, and January 1994);
- Most days with temperatures of 20° or less (28): from January 25 through February 21 (previous record, 27 consecutive days from January 12 through February 7, 1881), and
- Longest streak of days failing to reach 40° (43 consecutive): January 20 through March 3 (previous record, 42 straight days during winter of 1968-1969).

Timeline of Events

The convergence of two fronts (one moving from the west over Iowa, Missouri, Kentucky, Ohio and West Virginia and the other up the East Coast) prompted a spate of warning forecasts of imminent winter storm on the morning of January 26. Massachusetts Governor Charlie Baker issued a State of Emergency Declaration later that morning to take effect at midnight, January 27. The declaration included a ban on travel, in order to prevent motorists from being stranded on the road, and to expedite plowing efforts. In the end, what came to be called Winter Storm Juno, deposited 24.6 inches of snow and included blizzard conditions with
winds gusts of up to 75 mph along the coast and “white-out” conditions that disrupted the work of emergency responders and road crews. In its wake, Juno left massive snow drifts, coastal flooding, and significant wind damage. The travel ban and state of emergency were lifted on January 28 and the Metro area began to dig itself out. The MBTA, which had suspended service on January 27, reopened the next day, but with limited service. The winter weather was to set the city back on its heels, however, when another winter storm dropped 16 more inches on February 2 and 3.

Four days later, as the region continued to dig itself out and deal with Juno’s lingering snowfalls, Winter Storm Marcus roared into the Massachusetts Bay area with snow beginning to fall on February 7. Before the storm passed, Marcus had added 23.8 inches of snow to the already buried region. The Governor declared a second State of Emergency on February 9th as snow continued to fall and response and clearing efforts struggled to keep up. This State of Emergency remained in effect for two weeks before finally being lifted on February 25, 2015. In all the State Emergency Operations Center (EOC) was in operation for 28 days and some local EOC’s remained open for 87 days during the January through March period.

A fourth major snowstorm (though accumulation slowly continued in between) hit the region on Saturday February 14. The city received an additional 16.2 inches overnight and into the morning of February 15. As it was a weekend, Governor Baker did not issue an official travel ban on this occasion, however, he implored those going out for Valentine’s Day to be home by midnight, before the worst of the storm hit. In an attempt to inject business back into the severely damaged local economy, Baker dubbed the following week “Valentine’s Week” and urged residents to shop and dine.
The rapid succession of major snowstorms and daily freezing temperatures proved to be particularly disruptive for the Boston Metro Region’s mass transit system that supports daily commuters from as far away as Providence, Rhode Island and Worcester, Massachusetts. The MBTA was forced to suspend all functions to give crews a chance to clean tracks and shovel out stations. The subway, commuter rail, buses, and ferries closed on three occasions, once each for Juno and Marcus during the work week, and once on February 15 following the “Valentine’s Day” storm. Despite the best efforts of work crews on Sunday February 15, the next day saw the highest level of operational subway disruptions that winter.

With region-wide disruption of the transportation system, frustration mounted among commuters who could not get to work and their employers. Public officials added their voices to the growing chorus of complaints about shutdowns and delays of the subway and bus systems. On February 9, Governor Charlie Baker spoke out about the limited service on the MBTA, calling it “simply not acceptable.” In response, the beleaguered General Manager of the MBTA, Beverly Scott, called her own press conference and asserted that “to think that [the century old subway system] is going have the resilience to wind up rebounding and flying like an eagle, that’s the epitome of… and I’m not going to say ‘foolish.’” In the face of further criticism over her decision to suspend all MBTA service for 36 hours in February, Scott announced her resignation in frustration, to be effective in April.

Mayor Marty Walsh reflected the sentiments of a dejected city on February 15. In a press conference following the fourth major snowstorm, the mayor declared “I don’t know what to say to anybody anymore.” With so much snow and so little in the way of melt-off, the city was faced with the massive logistical challenge of finding places for the removed snow. Walsh soberly acknowledged to the city’s residents, “As you shovel, as you move the snow, it’s going to come back on your sidewalk.”

On March 15, the Boston Globe ran an article that bluntly announced “We did it… We broke the record.” That day the National Weather Service measured an additional 2.9 inches of snow at Logan Airport, putting the total snowfall accumulation at 108.6 inches and topping the
previous record by a full inch. It was a record that brought no celebrations. Just 12 weeks after meteorologist David Epstein's December 31, 2014 blog post asserting that it did not feel like winter, Boston had officially experienced a winter unlike any that Bostonians had ever dealt with before.

**Confounded Clean-Up**

Clean-up and recovery crews had only nine, mostly non-consecutive, days without snowfall between January 24 to February 25. This severely limited their ability to transition to long term recovery. Even on the few days without snowfall, there was no relief to be had from snow melt, as the persistent cold temperatures turned the piles of plowed snow into icy mounds on either side of the roads that made it nearly impossible for motorists to see around corners and confounded even pedestrian foot traffic. Car owners effectively gave up on digging out their vehicles, compounding the plowed mounds of snow with buried sedans and SUV's and turning intersections into what one resident described as “a blind game of chicken.”

Over the course of the winter, the city physically ran out of room to move the snow that was covering roads. USA Today reported that 25 million tons of snow had been plowed and dispositioned by early February – enough to fill the Patriot's stadium 90 times. Snow that is accumulated in piles, particularly where there are repeated cycles of re-freezing, becomes much denser than new fallen snow. Thus, movement of huge mounds of snow required lifting and hauling equipment, not just plows and blowers. While state agencies and private sector owners possessed some such equipment, they did not possess enough to deal with the immense volumes generated during the 30-day period. One bit of good fortune was that the surrounding Northeast region had not received nearly as much snow as the Boston area experienced. As a result, eight agencies from nearby states were able to provide through resource sharing agreements, 151 pieces of heavy equipment to assist in snow removal and management.

Massive amounts of snow were carried out of the city by dump trucks and stored in empty parking lots dubbed “snow farms.” The mountains of snow at these “farms” reached up to 75 feet high. In an effort to bring some humor to one of the most frustrating winters ever, Boston’s Mayor, Marty Walsh, took to Twitter to ask residents to guess when the snow at the Seaport District “farm,” the largest of them all, would melt, in a challenge he

![A before and after photo of the “snow farm” in the Seaport District](Source: Twitter - MEMA via @Conventures)
referred to as the "#BOSMeltNow Challenge." Because the core temperature of the snow piles remained much colder than the air temperature outside, it turns out that the correct answer was July 14, when MEMA posted a before-and-after photo of the pile and included the caption "#RIP."

**Impacts**

Under these severe winter conditions, the functionality of the Boston Metro Region’s critical infrastructure systems was severely compromised throughout the four-week period. Transit and health care systems took particularly heavy hits, but the region also had to deal with structural damage to residences and commercial building, power outages, and direct and indirect economic losses. The Massachusetts Emergency Management Agency (MEMA) completed a comprehensive incident report which provides a detailed analysis of the storms’ impacts. What follows are highlights of these effects within several critical categories: the transportation sector, health care, power, structural damages, and the regional economy.

**Transportation**

By far, the sector most seriously disrupted by the snowstorms was transportation. No mode was unaffected during the January 24 to the February 22 period. Pedestrian sidewalks and footpaths, ferry, air, rail, highways and city streets, buses and trolleys, commuter and light rail, and subways all experienced limited function with some being entirely shutdown during and following the major snowfalls.

**Roadways** were nearly impassable and travel was banned or limited for much of the 30-day period. MEMA reported that all totaled 315,753 miles of road were plowed during the four-week period with 114,057 tons of salt applied. The Massachusetts Department of Transportation (MassDOT) continuously deployed 753 personnel to deal with obstructed road conditions during the period, spending 34 percent more than their annual budget to support the effort. In addition, the Massachusetts Air National Guard (MANG) was tasked with 190 missions to support snow removal, clearing 120,564 cubic yards of snow and removing 2,964 truckloads. Not only did the road conditions confound vehicular traffic, but the snow piled along the verges covered bus stops and fire hydrants which MANG also cleared in order to facilitate buses as transit options, pedestrian safety, and fire response.

**Bus and shuttle services** were inevitably affected by deleterious road conditions and service was often limited, with frequent reroutes to negotiate increasingly narrowed street passage (from drifts and snowbanks) and one-way streets necessitated by challenging street conditions and snow removal operations. Five bus routes remained rerouted through April 1 where streets were most affected by drifts and snow piles.

**Commuter rail, light rail, and subways** bore the brunt of winter’s brute force on greater Boston’s mobility and transit. Because mass transit is so deeply interwoven into the fabric of community daily activity, its limitations and dysfunction were particularly corrosive to the
Boston Metro Region’s capacity for recovery and resilience. During the 30-day period of most intense winter conditions (January 23 through February 22) the MBTA experienced system-wide shutdowns of all operations on an unprecedented three separate occasions, leaving large sections of the metropolitan area normally dependent on the system for its transit needs immobilized. Official reports relate that on a normal workday, of the 3.3 million people in the Boston Metro area, 1.3 million riders use the MBTA to carry out their normal daily activities. Of those riders, 25 percent do not have access to a vehicle for personal transportation and rely solely on the MBTA for transit needs.

The MBTA exerted enormous effort throughout the period to deal with continually deteriorating operational conditions and yet was most often able to provide only limited service during significant stretches of the four-week crisis. In addition to the policy described by the MBTA General Manager and the Mayor as “all hands on deck,” the MBTA employed labor from 18 outside contractors, agencies and National Guard units (including those from nearby states) as well as “shovel brigades” made up of paid volunteers and groups of inmates, organized by the Department of Corrections. Despite these efforts, thousands of residents of the region were unable to reach work, school or medical appointments, virtually paralyzing normal activity.

Heavy rail portions of the system saw long term service suspensions and significant delays were part of daily operations from late January through the end of February. Buses, which had difficulties transiting the clogged and frozen streets, were pressed into service where rail tracks were impossible to open – offering some alternatives but not efficient ones. For much of February, the Red Line, which provides 270,000 trips each weekday for riders including many disadvantaged individuals who are most dependent upon the MBTA for transport, was severely disrupted by failures of traction motor units, propulsion line failures and impassable track conditions. For much of the four weeks, Red Line rail service was replaced by limited capacity bus and shuttle service. The Orange Line (200,000 trips daily) saw similar service reductions (20 percent to 55 percent during weekday operations) also from equipment failures and poor track conditions. The light rail Green line had intermittent terminations and numerous suspensions of service along all of its branches. Commuter rail was similarly affected with on-time averages dropping from its normal 88 percent level in the January week prior to the first significant snow to a low of 5 percent in mid-February. In addition, commuter rail equipment suffered heavily from the snow, salt treatments and subfreezing temperatures. According to
the MEMA report, “packed ice and snow along brake rigging, underframes, electrical connections and MU cables made connecting trains in the field extremely difficult and caused failures during service.”

**Rail service** into and out of the Metro region were disturbed by the treacherous track conditions created by snow drifts and frigid temperatures. All Amtrak service between New York and Boston was cancelled on January 27 with intermittent cancelations (of two trains or more) along the northeast corridor on the additional days.

**Commuter ferries** from Hingham Harbor and Hull were unable to operate at full service. From the week of February 1 through the week of February 22, the Hull ferry averaged 41 percent of its normal service; Hingham Harbor average just 31 percent.

**Air travel** was also diminished by the effects of the winter conditions. Over four weeks, 230,000 passengers suffered cancellations of 4,576 flights. Logan Airport authorities estimated that the direct loss from these events was $13 million.

**Health Care**
Throughout the Commonwealth, 25 deaths were attributed to factors stemming from the severe weather patterns. Blunt trauma injuries such as pedestrians struck by snow removal vehicles, falling off of roofs, or slipping on ice, caused seventeen of the fatalities and cardiac arrest resulting from snow removal activities were responsible for eight more. According to the Massachusetts Ambulance Trip Recovery Information System, over 1,500 people were transported to local hospitals, 1,320 from blunt trauma and 181 from exposure to the cold weather. Impacts to the functionality of the health care system, however, were of far greater impact.

Because of the extremely constrained transit and mobility choices available to medical and support staff during this 30-day period, clinical providers (in-patient, out-patient and residential) were forced to undertake extraordinary measures in order to provide critical health services. The Massachusetts Ambulance Trip Recovery System (MATRIS) data showed that the difficult road conditions had severe impacts on EMS response. On the “most heavily impacted days” 964 ambulance runs
experienced weather delays on at least one leg of their journey, with some runs experiencing multiple delays. All told there were 999 delays in transit (574 to a call and 425 to the hospital) and 214 on-site delays.\footnote{39}

Financially, hospitals had a significant loss of revenues while having to pay for the added costs associated with snow clean-up and emergency staffing measures. The four major Boston hospitals estimated $3.7 million in direct costs associated with snow removal to ensure patient and staff access, repair of structural damages, and overtime costs for staff. Brigham and Women’s Hospital alone reported $10 million in lost revenue from cancelled surgeries and reduced visitor numbers.\footnote{40} Further, because of the nearly persistent unavailability of reliable transportation, providers employed a number of tactics to have the required number of personnel available to maintain services and quality of care. These included multiple clinical care shifts, taxi vouchers, hotel rooms for staff, and in extreme situations, police transport of critical staff.

### Power

Electrical power providers fared reasonably well in maintaining their operations due to well-practiced protocols developed in response to earlier storms. Specifically, utilities had made a number of changes to mitigation, response, and recovery practices after outage experiences associated with Hurricane Irene. These changes, including preventative tree trimming and investing in additional equipment, positioned utility providers to better respond and recover.\footnote{41} Further, because the snow as it fell was relatively light in density, the relative impact of the winter storms on utility lines during the period was not as punishing as it might have been. At the peak of the winter conditions, approximately 34,000 customers lost power. Most outages occurred to homes on the South Shore with power restored within 24 hours.\footnote{42} Overall, the electric power sector had a marked improvement over the experience in 2013 when Winter Storm Nemo, the 5th largest snowstorm in Boston’s history, caused 100,000 outages.\footnote{43}

### Structural Damage

In all, there were 270 reported incidents of structural damage, affecting residences, commercial/industrial buildings, schools, government buildings, sewage systems, piers and seawalls.\footnote{44} Damages were primarily the result of high accumulations of snow and ice along with some coastal damage from wind and storm surge. The incidence of snow load and roof collapse was so extreme by late February that FEMA deployed a team from its Building Sciences

![Mounting snow caused a roof to collapse at an industrial complex in Hyde Park, knocking down adjacent electrical wires](Source: David Ryan/Globe Staff)
branch to forensically study accumulations and structural characteristics to better understand the collapsing phenomenon. The findings for this deployment have not yet been published.

**Economy**

With such paralyzing impacts to so much of the region’s transit infrastructure in particular, significant losses to the Metro Boston economy were inevitable. In an article published March 5, 2015, *USA Today* estimated that the January 22 to February 21 winter activity cost the region roughly $2 billion.\(^{45}\) MEMA’s estimated that the total direct costs/losses associated with the extended Arctic weather was $393 million, including $2.7 million of lost toll revenue to MassDOT.\(^{46}\) Small businesses in the Metro area reported 7 percent average drop in payroll and 22 percent average drop in sales. Retailers and restaurants reported a decrease in sales of nearly 50 percent.\(^{47}\) An American Highway Users Alliance study done of the economic cost of the snowstorms for different regions throughout the country, estimated that the cost of the transportation sector shutdown in the Boston Metro region was $265 million per day.\(^{48}\) This analysis also found that the winter disturbances had the greatest negative impact on hourly workers who accounted for almost two-thirds of total economic loss.\(^{49}\) Further, the study showed that loss of retail sales, income, and sales tax revenues doubled the initial economic effects of the shutdowns themselves.\(^{50}\)
Findings and Recommendations

The Boston Metro region’s experience with managing the significant disruption to lifeline infrastructure sectors as a result of the winter storms of 2015, provide helpful lessons for other regions that face the prospect of similar long-term, slow-moving meteorological disasters.

Finding 1

Current federal and state disaster laws, regulations and procedures are not written to adequately address long-term, slow-moving, extreme weather events.

At the time of the Boston snow storms, FEMA’s snow assistance policy limited assistance to a 48-hour window. The initial request by the state for a period of 28 days was rejected by FEMA because the request did not involve a single event. A subsequent request to extend the period to 72 hours was also rejected because an extension of 24 hours required a storm that exceeded any past records by 50 percent. The original request for the 28-day period would have met this requirement, while the more limited timeframe considered by FEMA policy did not.

The duration and unprecedented scope of this series of snow storms created a historically anomalous event that should lead to a reconsideration of current FEMA policy. As a part of his letter requesting implementation of the Federal Stafford Act, Massachusetts Governor Charlie Baker argued that the number and frequency of the snow storms combined with the consistently below-freezing temperatures created one severe snow event lasting from January 26 to February 22. He also pointed out that in the law, the exact verbiage on FEMA policy is: “The criteria listed in this policy are solely for use by FEMA in making recommendations to the President and in no manner restricts the ability of the President, in his discretion, to declare emergencies or major disasters.” He asked the President, thus, to “Define the incident period for the Major Disaster Declaration as January 26, 2015 through February 22, 2015 as a result of the near-catastrophic snowfall associated with the unprecedented, historic and unrelenting month-long weather pattern.” In the end, only 30 percent of the governor’s request for $400 million in federal

Governor Baker and President Obama shook hands at Logan Airport before the President spoke in Boston on Labor Day. The Governor said he thanked the President personally for his support during the visit. [Source: Andrew Harnik/AP via WBUR News]
disaster assistance was approved. FEMA agreed to pay the state only for the damages experienced during the first 48 hours of the month-long storm.

Massachusetts experience with soliciting federal disaster assistance highlights that the Stafford Act is currently not calibrated to take into account meteorological disasters whose destructive impacts are cumulative rather than instantaneous. FEMA snow policy as currently employed does not yet take into account the likelihood of increased incidences of long-duration snow storms in the heavily populated Northeast. The same potential problem is presented by long-duration, slow-moving events caused by naturally converging weather fronts that produce widespread watershed flooding or by drought conditions that extend the reach and duration of wildfires.

The likelihood that climate change will generate more extreme weather events of longer durations raises equity issues about how federal disaster assistance is provided. Addressing these equity issues will be important for sustaining ongoing public support at the national level for this critically important program.

**Recommendations**

- **Local emergency management and recovery officials** should prepare in advance for navigating the complexities of federal disaster assistance programs in order to hit the ground running in the wake of a qualifying event.

- **Federal officials** should consider changes needed in the Stafford Act or in FEMA’s interpretation of the President’s authorities under the Stafford Act to accommodate changing climate conditions and the destructive consequences associated with slow-moving, long duration extreme weather events.
Finding 2

A lack of a common situational awareness at both the metro regional and local levels, along with an inadequate understanding of the interdependencies across infrastructure sectors, leads to confusion and even occasional conflicts amongst and within agencies. Inevitably, this compromises disaster preparation, response and recovery efforts.

In many severe disruptions, decision makers are faced with the problem of obtaining reliable data about real-time conditions that could facilitate timely response and effective recovery actions. Lessons from the Boston snowstorm suggest that current response and recovery plans may not consider readily available social media and other data, and that a region’s social science community may be available to help officials both access this data and use it.

The paper, Post-Disaster Assessment: 2015 Boston Snow Storms, connected to this project and written by Dr. Daniel Aldrich and Courtney Page (Appendix A), describes a methodology for using social science data to identify and support the communities that may be particularly vulnerable to disaster and may require more support in response and recovery. Their recommendations describe how information about a community’s social capital and reliance on critical functions can be gathered and used to support both recovery planning before an event and response actions during an event in areas of significant need.

In a paper titled, “The Role of 311 Systems in Emergencies: Incorporating the Community into the Resilience of the Transportation System” (Appendix B), Dr. Dan O’Brien specifically examines the effectiveness of the Boston Metropolitan Area’s 311 System in aiding decision makers within the transportation system during the snowstorm.

Nationally, 311 systems have been created to allow residents to request government services using multiple communications channels – telephone, web portals and social media. In a disaster, such as the Boston snow storms, these requests for services can provide decision makers with one source of information which, in conjunction with other sources, can assist in resource allocation decisions for both response and recovery. In the case of the Boston snow storm, requests for snow removal both on the days of major snowfall and on the days immediately following provided a method of measuring community involvement in the metro area’s efforts to increase mobility.
O’Brien’s paper noted there were 36,138 requests for snow removal by citizens during the snow storms. After analysis of the data (available in the paper), the author concludes that neighborhoods with a greater reliance on automobiles or public transportation are more likely to request service using the 311 System and that social media may indicate more generalized frustration with conditions that manifest in complaints about the current disruption. Both papers in this report’s appendices indicate a significant potential for leveraging social data to assist planners in understanding and predicting where the most need for critical services will arise in a disaster and to help manage the response and recovery process when severe events occur. The engagement by emergency management professionals of social scientists in the development of metro area data collection may also be helpful in identifying the best ways to obtain relevant and understandable information and can significantly enhance decision makers’ understanding of the needs of vulnerable communities within the metro area.

To take advantage of these potential sources of data during crises, metro areas should also work to incorporate their most significant infrastructure owners and operators into their emergency operations centers either physically or via a robust communications regime. Communications between the citizen and the government will not be effective if information is not collaboratively shared with infrastructure operators. Infrastructure owners and operators must have a way to communicate their challenges and coordinate response throughout a metro area and public officials must be able to communicate community needs to the infrastructure owner/operators. In the aftermath of the Boston snow storms, the significant differences in the views of the Massachusetts governor and the general manager of the MBTA of the challenges facing the mass-transit system and the resultant confusion and frustration, illustrates the value of having such communications systems in place.

**Recommendations**

- **Stakeholders from the regional to the local level** should make better use of traditional and non-traditional sources of information, including 311 data and social media analysis to inform preparation, response and recovery strategies. Pre-disaster preparations should include information sharing between owners/operators and recovery coordinators.

- **Regional, city and local emergency management and recovery officials** should engage community-based social scientists to better understand where significantly vulnerable communities exist and the potential effects of those vulnerabilities during long-duration emergencies.

- **Metro areas** should develop a strategy for using a variety of social media platforms to enhance planning for response and recovery and should design a means to capture social communications during a long-duration disaster in a way that is useful and responsive to decision makers.
Finding 3

The rapid and full recovery of a metro region following a major disaster depends on a coordinated prioritization of effort across the multiple infrastructure sectors that collectively provide the essential functions people rely upon for their safety and well-being. Public, private and community leaders who collaborate in developing plans for bolstering resilience before a disaster will be better able to prioritize resources and make prudent decisions that reduce losses during a disaster and facilitate a speedy recovery in its wake.

American communities of all sizes depend upon a range of critical lifeline functions (energy, transportation, communications, healthcare, water) and social functions (education, workforce development, arts, entertainment, and recreation) to underpin an economically viable and meaningful way of life. Following a disaster, it is the restoration of these functions that allows commerce to resume and citizens’ lives to return to normal. While each of these functions are independently critical, they are also highly interdependent. Without the transportation of people and fuels, the energy sector will be crippled; without the energy sector, transportation is impossible. Both the transportation and energy sectors rely on a secure communications network for their safe and efficient operation. And communications networks need electrical power to function. Understanding and handling effectively the interdependency of a metro area’s critical services is indispensable to successful disaster management. Emergency response plans, while vital, are not sufficient.

The need for functional restoration plans is especially critical when dealing with long duration meteorological disasters. Such events can overwhelm contingency plans designed for hazards that have a clean start and finish. In the case of Boston, the tons of snow deposited on the metro area required daily efforts to remove snow over a period of several weeks. This created challenging logistical issues for storing and disposing of the cleared snow that were unanticipated. Each day’s accumulation of snow narrowed and sometimes blocked streets, roads and sidewalks, rendering many of them impassable. Additionally, plowed snow that was not carried away soon enough ended up becoming denser, making it increasingly difficult to remove without heavy-lifting.
equipment. The shortage of this equipment, in turn, resulted in dangerously high snowbanks forming along roadways which both inhibited further snow removal and rendered the roads hazardous for traffic and for pedestrians. E.J. Graff, a senior fellow at Brandeis University and Boston resident, described how car owners had given up on digging out their vehicles. The buried cars combined with piles of plowed snow made walking and driving a “game of blind chicken” when approaching an intersection, according to Graff.\textsuperscript{31}

The long-term snow accumulation led to the available snow farms being filled beyond their capacity. In the absence of alternatives, public officials had to make emergency requests to the Massachusetts Environmental Protection Department as well as to the U.S. Environmental Protection Agency for open water snow disposal despite the water pollution risk these measures pose.

Almost all critical infrastructure systems along with their owners and operators, whether public or private, operate across multiple political jurisdictions (i.e., municipal, county, and state), particularly in the densely populated U.S. northeast. This elevates the potential for misunderstandings and conflicts amongst decision makers at the very time when collaboration and cooperation is most needed. In Boston, this problem manifested itself early on with sharp differences publicly expressed between elected officials and the senior management of the Massachusetts Bay Transit Authority (MBTA). Had a well-coordinated, cross-jurisdictional, cross-sector transportation restoration plan been assembled in advance, many of these unfortunate conflicts may have been avoided. A noteworthy counter-example could be found in the energy sector which benefited from the Massachusetts Department of Conservation and Recreation’s (DCR) Winter Storm Management Plan and MEMA’s Statewide Power Outage Viewer. Another counter-example was the pre-existing arrangements put together by MEMA and the Boston Public Health Commission for managing health care situations. In both instances, public and private coordination worked well despite the unanticipated intensity and duration of the event.

The imperative to quickly restore commerce is particularly critical in the face of slow-moving, long duration weather events. As many community leaders have learned the hard way, small businesses are acutely vulnerable to extended disruptions of their businesses. Many of these businesses do not possess sufficient cash reserves or access to lending that will allow them to operate if they are shuttered for even a couple of weeks. Reenergizing a metro area’s commercial activity is heavily reliant on the restoration of power and communications to the businesses themselves, and the restoration of the transportation system that provides mobility for their work force, supply chains and consumers. In an event like the Boston snowstorm that caused such widespread disruption to the mass transit system, the resultant impact on
commuters and the associated business interruptions proved substantial. On an average weekday, 1.3 million riders use the MBTA. Of those, 25 percent do not have access to a vehicle. Because the system outages inordinately affected Boston’s largely blue collar neighborhoods of Dorchester, Mattapan and Roxbury, much of downtown Boston’s hourly-waged workers faced major difficulties getting to and from their workplaces. Some of the stations on MBTA lines had service suspended for up to three weeks (e.g., Ashmont Station trolley service) and while auxiliary shuttles were used extensively, these station closures resulted in long commuter lines and lengthy wait times. The effects on the resumption of commerce and the costs to metro area businesses were substantial.

For most states and major cities, emergency response and immediate recovery plans are largely based on historical precedent. An excess dependence on these plans can result in policies and procedures that actually undermine a speedy recovery when unplanned for and significantly different conditions arise. Extreme, slow-developing, long duration weather events (e.g., snow storms of high intensity with freezing temperatures over days and weeks and watershed flooding caused by long periods of heavy rainfall) create planning uncertainties that require a focus on understanding critical infrastructure sectors and their interdependencies at a regional level. Plans for managing disruptions must match accordingly. By focusing on identifying a minimal level of performance and restoration priorities for essential functions, community leaders will be better prepared to recover key services and economic activity in the face of catastrophic and unanticipated events.

**Recommendations**

- **Municipal and state officials** should work collaboratively on developing coordinated disaster recovery plans that, prior to a disaster, map out on a regional scale the infrastructure systems providing critical functions; e.g., electricity, transport, healthcare, communications, water supply and wastewater treatment. These plans should focus on sustaining and recovering lifeline functions in a way that takes into account the dependencies and interdependencies of infrastructure sectors. Ideally vulnerabilities
should be identified and mitigated through appropriate investment before disasters strike. Should these mitigation measures fail, there should be cross-sector guidance in place to prioritize the allocation of limited post-event resources to facilitate the most efficient recovery.

- **Metro-regional emergency management and disaster recovery officials** should ensure that all major owners and operators of critical systems, both private and public, are fully engaged and integrally involved in the recovery planning process. Additionally, community organizations, private business, and neighboring authorities, should be asked to help ensure the region’s assessment of critical functions, their interdependencies, and their recovery plan are thorough, accurate and practical.

- **State governments and major metro areas** should create full-time disaster recovery coordination positions with the authority to engage relevant public and private sector stakeholders. These personnel should be tasked with overseeing the development of a function-based metro-regional recovery plan. They should also be assigned the task of deciphering in advance of a potential disruption, the complex federal disaster assistance protocols and procedures so as to facilitate timely access to those resources.
Finding 4

Metro regions have economically vulnerable neighborhoods that are heavily reliant on public transportation, in-home or local healthcare services and clinics, and support from community-based non-profits to sustain their daily lives. These neighborhoods also often constitute the indispensable blue-collar workforce needed to help restore regional commerce in the event of a disaster. However, post-disaster restoration plans that focus primarily on restoring core city functions can risk overlooking the pressing life-safety needs of these vulnerable communities.

Not all communities within the Metropolitan Boston Area were equally affected by the snowstorm. More affluent communities and neighborhoods are less dependent on public services for food, mobility, and health care and were therefore able to cope with the snowstorm, inconvenienced but safe, secure and reasonably productive. However, neighborhoods with relatively high numbers of residents who are economically disadvantaged, have special needs, or are disabled may quickly face desperate conditions if they are cut off from caregivers due to the loss of mass transit and when the local stores, pharmacies, and food distribution networks they rely on are not able to operate. They are also usually less able to communicate their needs to public officials because of language or cultural barriers, or lack of access to phone and internet services. These vulnerable populations need to be identified by communities in advance and assigned a higher priority for restoration of critical services.

Within the city of Boston, the neighborhoods of Dorchester and Mattapan offer compelling examples of areas that are highly dependent on public services and require focused attention during severe, long-term disruptions. The loss of MBTA services was particularly difficult for residents of these economically challenged neighborhoods, as many do not have access to vehicles. As urban property values are often positively correlated with ease of access to public transportation, inevitably, poorer residents live in areas that require them to travel longer distances by walking or by bus to gain access to the wider mass-transit system. In the case of Dorchester and Mattapan, residents rely extensively on the Ashmont-Mattapan

Commuters wait for hours outside for their turn to board one of the shuttles that replaced suspended Red Line service. (Source: @JKrowchun/Twitter)
Trolley to reach the subway system. However, this trolley was assigned a low priority in the MBTA’s plans for restoration of service and was completely out of service for three weeks in February. Those who were able to negotiate a way around the trolley and reach the main Red line then found long lines waiting for limited service in sub-freezing conditions. For the many hourly-wage workers living in Mattapan and Dorchester, who were not able to make it to their jobs, the resultant loss of a paycheck created an additional financial burden to cope with.

The loss of income in these communities is not the only economic consideration in understanding long-duration disruptions on disadvantaged communities. It is also important to understand that much of the blue-collar workforce resides in these communities. The economic life of a city depends as much on maintenance workers, cooks, janitors, and drivers as it does on business executives and shopkeepers.

Dorchester and Mattapan are neighborhoods that also have significant populations of disabled residents and residents with special medical needs that were physically unable to leave their homes. The snowstorm and the resultant limited means for mobility that it created was especially challenging for providers of home and distributed health care (local clinics, dialysis centers). Meanwhile the major hospitals were stressed by additional workloads and staff shortages. There were over 1,500 weather-related injuries that required some level of hospital engagement. Non-emergency surgeries were cancelled as hospital bed capacity was exceeded throughout the metro area. Not only was it difficult for hospital staff to get to work, but EMS response was also severely affected. On the days where snowfall and road conditions created the most difficulties, 964 ambulance runs experienced weather delays on at least one leg of their journey with some runs experiencing multiple delays. In all there were 999 delays in transit and 214 on-site delays. In communities already experiencing chronic health challenges, the snowstorm added significantly to health care disruption.

Restoration of critical infrastructure in metropolitan areas is frequently, and logically, driven by good engineering practices and sound management procedures that assign first priority to the restoration of functions that supports the most users. While this is generally appropriate, communities should also analyze in advance the likely impacts of potential disruptions for special needs residents and for those who are most economically disadvantaged. They should also consider the often disproportionately important role in the wider restoration of regional commerce that is played by the blue-collar workforce that may live on the outer edges of a city’s mass transit system.

**Recommendations**

- Local, state and regional efforts to restore functional capacity, particularly of critical infrastructure systems (e.g., rail lines, bus services, electrical power, water and waste
water) must balance the optimization of engineering/business practices with the life-safety needs of the most vulnerable communities.

- **Local and state governments** should partner with community organizations that understand the needs of their most vulnerable communities, and establish strong partnerships and clear lines of communication that can be leveraged by both sides in the wake of a disaster.

- Long term recovery plans should recognize the important role that hourly-wage earning residents play in the economic recovery of a metro region, writ large, and strive to ensure they have early access to public transportation.
Finding 5

The very nature of our metropolitan areas – the way they are organized, owned, and operated in normal times – dictates that government alone cannot effectively respond to nor recover from disaster. Fortunately, there is significant untapped capacity within civil society and in the private sector to support response and recovery efforts during and after disasters.

The best metro area governments harness the power of the entire community; they treat their businesses and citizens as partners in recovery rather than as problems to be overcome. This partnership will not work, however, without the social capital that facilitates communications and builds trust. That social capital cannot be built in crisis. It must be deliberately engendered during the blue-sky days well before disaster strikes. It must include all segments of the society. And it must be an integral part of the metro-area’s normal way of daily operations.

Described in greater detail in Appendix A, there is strong evidence that a community’s resilience to severe shocks relies heavily on social networks and the trust that they create. As stated there, “Communities that trust decision makers and believe that their opinions are taken seriously are more likely to support and facilitate attempts to implement new public policies such as price changes, planning meetings and policy feedback.” This type of trust facilitates public compliance with difficult emergency directives whether it be parking bans during severe snow storms or evacuation before potential flooding or storm surge. It also engages the public to act in their own interest.

To capitalize on the resilience that comes with social capital and trust, metro-leaders must fully understand their local social conditions, and do so through open pre-disaster dialogue and engagement. A deliberate mapping of vulnerability and the effects of loss of critical functions, whether publicly or privately provided, on vulnerable communities is critical. The Mattapan and Dorchester areas of Boston were examples of communities vitally reliant on public transportation, but who had difficulty communicating their needs in ways that reached the state agency officials responsible for making system restoration prioritization decisions.
Metro area officials must also find ways to actively build social capital in vulnerable communities. Actions should include frequent attendance at community meetings, and outreach and engagement with the social centers of community life (e.g., churches, shelters, workplaces). They should also strive to be responsive to valid neighborhood concerns about everyday life and safety issues. Strengthening horizontal integration – neighbors, close family, and community and faith-based organizations – within the community is also critically important. These represent the support structures when government is not or cannot be active. Efforts by metro-leaders to reinforce these horizontal structures can have significant benefits in times of crisis.

The private sector, which owns and operates significant sectors of the metro-area’s critical infrastructure, provides by its very nature much of the capacity for response and recovery. Seldom, however, is it fully incorporated into metro-area planning pre-crisis or response during a crisis. Several states and many metro-areas have found that Business Emergency Operations Centers fully incorporated into governments’ Emergency Operations Centers can be powerful amplifiers of response and recovery efforts. In the Boston snow storms, commercial bus service was provided to supplement some of the lost MBTA capacity through a post-storm arrangement between the state and the Peter Pan bus company.62 This proved to be highly effective and was put together quickly because of the company’s responsiveness to providing service in the emergency and a willingness to determine price later.63 However, the arrangement may not have come to fruition if Governor Baker had not reached out to Peter Pan to ask for help, and if the Boston Carmen’s Union had not provided its approval.64 Though Peter Pan has provided assistance in the past during track repair,65 a pre-existing, contingency contract for disaster situations could have worked even better.

**Recommendations**

- **Metro regional government stakeholders** should prioritize bolstering social capital within their region, and should incorporate the assistance that civil society can provide in supporting recovery efforts. Contracts with private businesses should be established
before a disaster in order to expedite and optimize cooperation and mutual assistance during a disaster.

- **Infrastructure owners and operators** should take action to ensure metro area decision makers understand the likely effects of loss of critical functions in vulnerable communities through a deliberate planning process and sustained engagement with those communities.

- **City and local leaders** should fully integrate the private business sector into disaster response and recovery planning to allow access to the full power of private business capacity during disasters.

- **Emergency managers** should consider the integration of a business emergency operations center within their city emergency operation centers.
Finding 6

Underinvesting in maintenance and upgrades to legacy infrastructure systems nearly guarantees that they will fail badly when disasters strike, putting lives at risk, undermining economic competitiveness, and eroding public confidence in their elected leaders.

There is a growing need for major investments in maintaining and upgrading legacy infrastructure, and constructing new infrastructure that supports functions that are critical to the social and commercial lives of major metro regions. The devastation associated with major disasters is often directly correlated with the age and neglect of the built environment upon which a community depends. The forecasted increased frequency and intensity of disasters reinforces the need to make investment in infrastructure an urgent national priority.

The back-to-back Boston snowstorms and extended period of below freezing temperatures was an unusual event. Its impact on the metro area’s built infrastructure would have been significant under any circumstances. However, there is little question that longstanding underinvestment in the region’s MBTA mass transit system did not position it for success. The routine deferment of work to address the well-documented needs of a century-old transportation system exacerbated the challenges associated with recovering the system and severely affected the metro area’s rapid return to normalcy.

At the outset, it is important to note that Boston is not alone in neglecting its aging infrastructure. The American Society of Civil Engineers has assigned an overall grade of D+ for America’s infrastructure with an estimated investment of $3.6 trillion needed by 2020.66

For the Boston Metro region, the MBTA is indispensable to supporting daily and commercial life. Over 3.3 million people live within half mile of the system’s stations.67 On an average weekday, over 1.3 million use the system and of these, 25 percent do not have access to a vehicle.68 Parts of the MBTA system are the oldest underground transit in America and date back to its opening in 1897. For years, Boston has focused on rehabilitating aging equipment rather than replacing it. One third of the Red Line’s 218 cars were built in 1968 and 1969 and are still running after a rehabilitation

Commuters faced substantial delays along the Red Line on February 3, 2015 as the T’s aging infrastructure struggled to keep up with the onslaught of severe winter weather. 
(Source: Edgar B. Herwick III/WGBH News)
program in 1985 and 1986. Another 58 cars were built between 1987 and 1989. The Orange Line is even older, with all 120 of its cars built between 1979 and 1981. The design life for these cars is 25-to-30-years, placing them at or beyond the time when they should be replaced.

In the 2015 snowstorm, it was this aging equipment interacting with the system’s above ground sections that caused the most problems. All above ground lines saw disruption caused by frozen tracks, frozen third rails, inoperable switches, inaccessible storage facilities, disabled trains, or snow covered stations. One particular issue that could have been mitigated with prior investment is an aging third rail, pockmarked with grooves and contours that made it susceptible to filling up with difficult-to-clear ice and snow. On February 9th, a Red Line train lost power as a result of this snowy third-rail buildup and over 40 passengers were stuck for two hours on their morning commute. Following the storm, Massachusetts Governor Baker made replacing these abused third-rails with modern aluminum upgrades a priority of his winter resiliency plan.

Another example where resilient infrastructure investment decisions could have eased the winter’s pain can be seen in the use and failure of the MBTA’s direct current traction motors. At the start of the winter, over half of train cars on the MBTA’s Red Line and every car on the Orange Line were driven by this motor, a technology described in 2005 by the head of Chicago’s Transit Authority as “becoming obsolete.” In conditions of light, snow accumulation, snow is sucked into a traction motor’s filtration system, where it melts and can short out direct current electrical components. Dozens of traction motors failed this way in the 2015 winter, forcing the MBTA, at times, to operate only half of its Red and Orange Line trains. General Manager of the MBTA at the time, Beverly Scott, attributed the widespread failures directly to lack of investment. “If, years ago, the authority had had the money and funds to do a midlife overhaul and replace and upgrade the propulsion system, the traction motors would have been updated with them,” Scott said, “But some things you don’t get to pick and choose.”

Compounding many of the transit system’s delays, a lack of sufficient, specialized track-clearing equipment to deal with the extreme snowfall conditions resulted in

Snow buildup on the Red Line’s tracks caused a power failure that stranded this train for over two hours. (Source: Twitter – Scott H @ScottieH_07)
in a significant reliance on human labor. Shovel brigades were required to manually shovel and clear more than 15 miles of above ground tracks and thaw switches. There were three occasions where the entire system had to be shut down because of the snowfall. In the end, the system did not return to full functionality until April, almost three months after the storm. In some cases, buses were used as an alternative for the closed subway stops on the Red and Orange lines but there were no surface transportation alternatives for those on the Green line, a critical link in the system.

These disruptions were particularly challenging to workers living in the Boston neighborhoods of Dorchester and Mattapan. These two areas lie near the end of the Red line and are populated by a significant part of the hourly labor force for the downtown metro area. On a typical workday almost 2,500 people use the connecting Mattapan-Ashmont trolley to reach the main Red line at Ashmont Station. The trolley, completely dependent on above ground tracks, was suspended for three weeks in February. The MBTA did provide shuttles to substitute for the loss of the trolley but the long lines in sub-freezing temperatures created dangerous conditions and caused many workers to be late or not to able to get to work at all.

The costs of the MBTA disruptions were extensive. Initial estimates revised over time indicate that the costs to the system from snow removal, infrastructure repair and lost revenue exceeded $40 million. Snow removal alone exceeded the annual budget by 397 percent. Commerce across the region was also substantially disrupted by the loss of capacity on the MBTA. In addition to workers not being available to reach their places of work in the center of the city, small businesses normally fueled by commuter foot traffic moving to and from MBTA stations throughout the system were heavily impacted. The full economic loss has not been calculated and economists have different views of the extent of loss due to snowstorms. However, the Boston Globe reported that the research firm IHS Global estimated that a one-day storm costs the Massachusetts economy $265 million with 75 percent of that resulting from lost wages.

Going forward, the challenge for public officials, infrastructure owners and operators, and communities nationwide will be to finance the maintenance of the critical infrastructure sectors that support modern life and economic vitality, while marshalling the additional resources to ensure that critical infrastructure can handle the risks associated with changing climate conditions. Failing to do this will result in lives needlessly disrupted and placed at risk, as well as an ongoing erosion of national economic competitiveness.
Recommendations

- **Metro regions** should require city planners, public works officials, business leaders, emergency managers and recovery personnel to work together in developing a prioritized list of infrastructure investment opportunities that take into account the lifeline functions essential to the region, critical interdependencies, and novel research, designs and technologies.

- **Public and private infrastructure owners** should, where possible, examine insurance options such as catastrophe bonds that encourage resilience-enhancements and recognize regional interdependency challenges and the threat of cascading failures.

- **Public education campaigns** should be developed and deployed to raise greater public awareness of the critical foundations that communities rely on as well as the associated financial and operational requirements for ensuring that infrastructure sectors can provide their critical functions efficiently and safely.
Conclusion

The snowstorms of 2015 presented the Boston metropolitan area with a largely unanticipated series of challenges that affected every aspect of urban life and stressed the city, surrounding communities, the state, and region to record levels. These snowstorms over a period of several weeks provide a compelling example of the challenges connected with a changing climate: slow-moving and long-duration extreme weather events. They exposed important interdependencies among aging lifeline infrastructure sectors that are struggling to keep up with the demands of a growing number of users who rely on them. And in some of Boston’s most disadvantaged neighborhoods, the storms revealed how deeply dependent the most vulnerable populations are on public transportation for access to life-sustaining health care and other elemental needs.

Examining this event for lessons learned highlighted the importance of better anticipating the potential for cascading failures across interdependent infrastructure systems. The event also served as a reminder that, while there are always constraints on the resources available for maintaining and upgrading infrastructure, the cost of not making these investments can be catastrophic when disasters strike. Going forward, better sources of data and closer public-private information sharing arrangements will help to enhance disaster preparation, response and recovery in the Boston metro region and in metro regions around the country. Communities should also prioritize the building and strengthening of social capital and the trust it engenders on blue-sky days in order to better assure a rapid, equitable recovery in the aftermath of the stormy ones. Finally, long-duration, slow-evolving events need new procedures and processes to better align state and federal disaster assistant resources for meeting the requirements of these distinctive kinds of emergencies.

As Americans continue to learn from and cope with a multitude of complex 21st century disasters, the experience of the Boston region during the 2015 snow storms provides a clear pathway for communities, states, and the nation to more confidently meet a turbulent and uncertain future.
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Appendix A

Post-Disaster Assessment: 2015 Boston Snow Storms
Mapping Impacts on Transportation and Social Networks and Vulnerabilities

Daniel P. Aldrich, PhD
Courtney M. Page, MPA, MA

Photo Credit: David L. Ryan/The Boston Globe/Getty Images
Executive Summary

● While decision makers may intuitively focus on system optimization during crisis, we suggest instead using available social science data to identify and support vulnerable groups who will be hardest hit during disaster.

● Those who live closer to and rely upon public transportation nodes were more likely to be negatively impacted by the service suspensions of Boston buses and subways during the 2015 snow storms.

● These individuals had fewer social ties and weaker safety nets before the disaster, making them doubly vulnerable during the crisis.

● These vulnerable individuals also did not take advantage of existing channels of communication to alert policymakers to transportation and infrastructure issues in their communities.

Background

The continuous subzero temperatures and unrelenting Polar vortex turned the middle of the 2014-2015 Boston winter into a disaster. The months of November and December of 2014 were uneventful, with snowfall from November and December totaling three inches, well below the average. In December alone, Boston typically sees an average snowfall of 12 inches (Lipman 2015). However, beginning in late January, a series of snowstorms, each unloading devastating payloads upon the city of Boston, made January and February of 2015 unforgettable. As Figure 1 below displays, the amount of snowfall which fell in the short period of 2015 dwarfed the snowfall from 2014 and 2016.

A total of 110.6 inches of snow fell on Boston over a short period of time, surpassing historical records back to 1872. Over the course of 33 days between January and February, the National Weather Service recorded 24 days of measurable snowfall in the Boston area (MEMA 2015). In response, the Massachusetts State Emergency Operation Center was open for 28 consecutive days and Local Emergency Operations Centers were active in 87 cities.

On January 25th, a nor’easter, low-pressure hybrid hurricane-like storm systems that occur frequently along the East Coast caused by unusually warm temperatures in the ocean (Halverson 2016: 13), dropped about two feet of snow on the city of Boston. Over the next week and half, two more record setting blizzards hammering Boston. By mid-February, the city was buried. The colder than usual temperatures in Boston offered no relief as the cold weather prevented the snow from melting. Instead, each record breaking snow accumulation halted business as usual, paralyzed the transportation system, and left many families vulnerable. More specifically, many residents found themselves unable to reach their places of work, doctors, and schools. Locals who relied on in-home care from extralocal caregivers had to struggle by themselves or with the assistance of neighbors and family. Thousands of patients who had scheduled visits to receive drugs or treatment struggled to reach their medical providers.
On January 26th, Massachusetts Governor Charlie Baker issued a state of emergency and banned statewide travel for the duration of the storm (Pattani, Ellement and Finucane 2015). Two blizzards later, on the eve of Monday, February 9th of 2015, subway and commuter rail services throughout Boston were suspended. While bus services were still running, service remained on limited basis. In response to these decisions, Massachusetts Governor Charlie Baker expressed his disappointment, stating that “When the weather is as bad as it has been lately, the public transportation system needs to work.” (“MBTA Suspends Rail Service” 2015). Four days later, the MBTA suspended all service for another day (Pattani and Finucane 2015).

In addition to MBTA service suspensions the weekend of February 13th, Boston Mayor Marty Walsh issued a parking ban across Boston neighborhoods to clear the streets of snow, Logan airport canceled all of its flights for Sunday, February 15th and the Pilgrim nuclear power plant in Plymouth went offline as a precaution (“Boston Parking Ban” 2015). Boston residents had just a few hours to move their cars from the streets, and as one resident Tweeted with a picture of a car being towed, “the Mayor meant it: move your cars!” (Payne and Castillo 2015)

Among the thousands of MBTA customers who rely on subways and buses on a daily basis, those in Dorchester and Mattapan who relied on the Ashmont-Mattapan Trolley had to find another way to work for almost three weeks during the winter storms. The Ashmont-Mattapan Trolley connects riders to the Ashmont T station on the Red Line. Its service was suspended from early February until it reopened on February 23rd (Dezenki and Atkinson 2015). On a typical weekday, the Ashmont-Mattapan Trolley makes 326 one-way trips. More well-known subway lines, such
as the Red, Orange or Blue, make an average of 438, 324, and 354 one-way trips on a weekday, respectively (MBTA 2014: 5). On a typical weekday, 2,356 riders rely on the Ashmont-Mattapan Trolley for inbound service to Ashmont Station (MBTA 2014: 26). For residents of Mattapan and Dorchester, two of the most vulnerable communities in the city of Boston, this service suspension was a double whammy. According to local State Rep. Dan Cullinane, “Three weeks is far too long for the people who rely on the Mattapan Line.” (Dezenki and Atkinson 2015)

**Timeline**

Collectively, there were five storm systems that pummeled the Northeast between January 20th and February 14th. The National Oceanic and Atmospheric Administration (NOAA) developed a Regional Snowfall Impact (RSI) Scale in 2005 to convey the amount of snowfall, the geographic scope of storm and the societal impact of the storm based on population (Squires et al. 2014). The scale provides a useful metric to understand the scale and impact of the storm real-time and in historical context. NOAA classifies individual storms across five categories based on their RSI value (see Table 1).

**Table 1: Storm classification**

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>RSI VALUE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1–3</td>
<td>Notable</td>
</tr>
<tr>
<td>2</td>
<td>3–6</td>
<td>Significant</td>
</tr>
<tr>
<td>3</td>
<td>6–10</td>
<td>Major</td>
</tr>
<tr>
<td>4</td>
<td>10–18</td>
<td>Crippling</td>
</tr>
<tr>
<td>5</td>
<td>18.0+</td>
<td>Extreme</td>
</tr>
</tbody>
</table>

*Source: NOAA*

While the most devastating storm (January 25, 2015 – January 28, 2015) was categorized as ‘Major,’ in fact the combination of a series of heavy snowfalls along with continuing freezing temperatures created a disaster. On the whole, the sum of RSI indices of these five storms is equal to 12.292, considered to be a ‘Crippling’ storm according to NOAA’s scale (see Table 2).

**Table 2: 2015 Boston snowstorm timeline**

<table>
<thead>
<tr>
<th>Snowstorm</th>
<th>Category</th>
<th>RSI Index</th>
<th>Boston Snowfall (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 20, 2015 – January 24, 2015</td>
<td>0</td>
<td>.491</td>
<td>2.4</td>
</tr>
<tr>
<td>January 29, 2015 – February 3, 2015</td>
<td>1</td>
<td>2.606</td>
<td>16.2</td>
</tr>
<tr>
<td>February 8, 2015 – February 10, 2015</td>
<td>1</td>
<td>1.897</td>
<td>23.8</td>
</tr>
<tr>
<td>February 14, 2015 – February 16, 2015</td>
<td>1</td>
<td>1.140</td>
<td>16.2</td>
</tr>
</tbody>
</table>

*Source: NOAA, ‘Boston Snowfall’ readings from the WINTHROP 0.2 N, MA US NOAA weather station*
Methods

Boston is a city geographically divided along sharp racial and economic lines. In this study, our team placed an emphasis on understanding the impact of the Boston snow storm on public mass transportation systems (primarily those managed by the Massachusetts Bay Transportation Authority, or MBTA) and how bus and rail shut-downs interacted with vulnerable populations in the Boston area.

Geographically, we focused on the communities in the areas of Mattapan, Roxbury, and Dorchester, as past research has identified many residents in those areas as vulnerable. We developed and administered an original survey in these communities (see the addendum at the end of this report for complete survey). Figure 2 below captures the locations of our respondents. We used multiple channels to collect data on the individuals and communities affected by the 2015 snow storms. We used three primary methods: 1) face to face interviews with residents, 2) mail surveys, and 3) online surveys. Our total number of respondents was 153, with the bulk coming from 60 surveys returned via post; we also received 35 online responses initiated by our mailing, 47 from face to face interviews, and 11 responses from surveys taken in person. We used multiple methods not only to try to ensure that we had a more representative cross-section of neighborhoods of the city in which we have an interest. Using more than one way to capture local conditions allows us to try to move past any errors that we may find from a single type of survey - whether online (where respondents are typically younger and wealthier) to in person (where, depending on the time of day, gender may strongly determine who answers the questions).
We define *vulnerable* as those residents who live in communities with low levels of social capital. “Family, friends, and associates constitute an important asset, one that can be called upon in a crisis, enjoyed for its own sake, and/or leveraged for material gain” (Woolcock and Narayan 2000: 3). Our use of the term social capital references the “networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit” (Putnam 2000: 67). Building on empirical evidence that resilience to shocks and disturbances depends heavily on the social networks and trust between relevant players and local communities (Aldrich 2012; Dynes 2006; Chamlee-Wright 2010; Prasad et al. 2014), we understand that communities with deep reservoirs of social capital can more successfully overcome shocks and crises. For example, in such communities neighbors may provide material assistance, information, and emotional support. Residents who know each other may work collectively to clear snow from the driveways and sidewalks of the elderly, go out to purchase medicines for shut ins, and help the vulnerable with their daily lives by bringing in groceries, warm clothes, and emotional support. Horizontal ties to neighbors are not the only critical social resource. Communities that trust decision makers and believe that their opinions are taken seriously are more likely to support and facilitate attempts to implement new public policies, such as price changes, planning meetings, and policy feedback. The most resilient communities would be ones that had both strong horizontal ties (to
neighbors and nearby friends and family) and vertical ones (to decision makers and authorities with access to critical resources).

Based on our operationalization of vulnerability, our team created a social capital index to capture the levels of civic engagement, social cohesion, and trust in communities in the Boston area at the Block group level. Our index consists of twelve indicators from ESRI Business Analyst, equally weighted to serve as a measure of civic, philanthropic, and religious engagement (see Table 3 below). Block group, a geographic unit used by the U.S. Census Bureau to identify a cluster of blocks with 600 to 3,000 people, resolution of the data gives a fairly precise portrayal of social capital in communities. Based on our index, we conducted a Hot Spot Analysis. This allowed us to identify statistically hot and cold spatial clusters of social capital. This analysis yields a z-score, p-value and confidence level for each Block Group. To account spatial dependence, we used a False Discover Rate (FDR) Correction parameter to ensure the spatial analysis is robust.

**Table 3: Social Capital Index**

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attended public meeting on town or school affairs (%)</td>
<td></td>
</tr>
<tr>
<td>Served on committee for a local organization (%)</td>
<td></td>
</tr>
<tr>
<td>Engaged in fundraising in the past 12 months (%)</td>
<td></td>
</tr>
<tr>
<td>Volunteered for a charitable organization in the past 12 months (%)</td>
<td></td>
</tr>
<tr>
<td>Wrote or called a politician in the past 12 months (%)</td>
<td></td>
</tr>
<tr>
<td>Voted in federal/state/local election the past 12 months (%)</td>
<td></td>
</tr>
<tr>
<td>Attended a political rally/speech/organization protest (%)</td>
<td></td>
</tr>
<tr>
<td>Contributed to a political organization in the past 12 months (%)</td>
<td></td>
</tr>
<tr>
<td>Contributed to a religious organization in the past 12 months (%)</td>
<td></td>
</tr>
<tr>
<td>Contributed to a social services organization in the past 12 months (%)</td>
<td></td>
</tr>
<tr>
<td>Contributed to a health organization in the past 12 months (%)</td>
<td></td>
</tr>
<tr>
<td>Contributed to an educational organization in the past 12 months (%)</td>
<td></td>
</tr>
</tbody>
</table>

We used several ways to analyze the data, including GIS-based analytical tools and cross-tabulation with chi-squared tests.
Findings and Recommendations

Finding 1: Decision makers need to look beyond system optimization during disaster to those with greatest needs; we suggest that they look to social science data to allocate resources.

During disaster, authorities may seek to invest resources to keep overall systems running, focusing on restoring all services in a specific field, such as transportation or energy. Yet our data show clearly that not everyone experienced the snowfall and subsequent shutdown of public transportation in the same way. Vulnerable communities in Boston described more severe impact to their daily lives, commutes, medical upkeep, and jobs than more resilient ones. Some communities and neighborhoods may have both the material and social resources to survive independently for several days, while others display a strong dependence on outside assistance. The neighborhoods most affected in our study were those most reliant on existing transportation networks who lacked access to self-owned private vehicles. Should decision makers have to choose between clearing the train tracks, bus routes, or roads used primarily by private cars, our data show that public transportation routes should receive special attention.

As 311 data analyzed elsewhere in this report illuminated, the most vulnerable may be less likely to report issues or problems to authorities and may need to invest more in maintaining daily activities during disaster. Rather than envisioning disasters as times when they can rely on feedback from communities, authorities need to proactively use publicly available data in conjunction with reporting from local NGOs and experts to better assess which areas will need help most. Our maps have identified a number of hotspots throughout the Boston area. Other cities, counties, and regions could easily replicate our approach with publicly available data.

Residents in vulnerable communities, as we lay out below, also face the double jeopardy of higher reliance on public transportation while living in communities with less social support. Should their normal child care provider be unavailable, they may have a harder time finding a replacement on the fly. Should they experience a disruption in their commuter schedule, they may not be able to make scheduled medical appointments.

Our research has shown that communities with strong horizontal ties to each other and good vertical ties to decision makers in city hall, regional government, and local NGOs and faith based groups are the most resilient during catastrophe. Those communities which lack these ties, in contrast, see themselves as less able to deal with challenges such as excess snowfall and more likely to report disruptions to their daily schedules and lives. We want our residents to feel that they are part of the city and that their views are taken into account. Our data showed that individuals who felt that their opinions were taken seriously - a condition social sciences call efficacy - also felt that they were best prepared for future disasters.

City level authorities should make sure that their decisions take into account knowledge of local social conditions along with data on hotspots detailing transportation dependency and social ties.

Finding 2: Those who lived closer to bus and subway stops were more likely to be negatively impacted by the MBTA service suspension during the 2015 snow storms.

We combined GIS data on distance from the subway with the responses from individuals to our surveys and questions. Below in Figure 3 we bring this information together into a single diagram.
We have created buffers around subway stops which range from dark green (.25 miles) to dark red (2 miles). Then, we identify each respondent based on whether they were affected by the snow determined by their response to the following prompt: “Please check all that apply: “As a result of the MBTA service suspensions during the 2015 snow storms, I ...”” options including: suffered wage losses, missed a scheduled hospital/doctor/dental appointment, missed work, missed school or experienced a negative health outcome. Those indicated at least one response to the prompt, we coded as “Affected” indicated in red in Figure 3, and those who did not, we coded as “Not Affected,” indicated in grey. We can see a number of respondents indicating that the snowstorm affected their daily lives from the concentration of red dots. Further, those who have homes, apartments, and condominiums closer to subway nodes seemed to have higher rates of being affected than those who live further away.

Figure 3: Distance from Subway Stops

**MBTA Stops and Subway Lines: MassGIS Data**

To further confirm this relationship between distance and storm effects, we ran a bivariate analysis of the relationship between distance from the nearest MBTA node and whether or not respondents indicated they were affected by the event based on their responses. Chart 1 below provides additional evidence that in our sample, there was a statistically significant relationship between smaller distance to the MBTA and being effected by the storm. Using the chi-squared test, we can see that people who lived closer to public transportation nodes were more likely to report being affected by the MBTA shutdowns.
Chart 1: Cross tabulation of distance and effect

<table>
<thead>
<tr>
<th>Distance from MBTA</th>
<th>Affected by MBTA Transit Suspension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td>(miles)</td>
<td></td>
</tr>
<tr>
<td>0-5</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>18.5</td>
</tr>
<tr>
<td></td>
<td>24.00</td>
</tr>
<tr>
<td>.51-1</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>15.2</td>
</tr>
<tr>
<td></td>
<td>48.78</td>
</tr>
<tr>
<td>1.01+</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>55.56</td>
</tr>
<tr>
<td>Total</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>37.0</td>
</tr>
<tr>
<td></td>
<td>37.00</td>
</tr>
</tbody>
</table>

Pearson chi2 (2) = 7.3954
Pr = 0.025

Recommendations:

**Local Communities:** In the course of this research, immediate family (48%), neighbors (38%) and close friends (21%) were most useful to survey respondents seeking to resume life as normal after the storms. This being the case, we recommend local community leaders from local Boston organizations such as Grove Hall’s Project RIGHT, the Four Corners Neighborhood Association and International Sustainability Guild, the Codman Square NDC and the Codman Square CHC, The Boston Project Ministries in the Talbot-Norfolk Triangle Neighborhood and Mattapan United seek to invest in opportunities for community members to further develop and strengthen ties. Broadly speaking, examples may include programs that encourage community service and citizen engagement, as well supporting extant community-based organizations that provide a forum for community feedback. These programs can serve as conduits for community services coming from outside organizations such as city hall and NGOs as well. In doing so, we expect reservoirs of social capital will deepen, therefore, creating a resource that is not only useful amid and following a disaster, but one that yields numerous positive externalities.

**The City of Boston:** As our findings suggest, those who live closer to the MBTA, and therefore presumably have more reliance on its services for daily activities, were more likely to be affected by the MBTA service suspensions during the snowstorms. Further, survey respondents identified the MBTA (47%) and the City government (27%) as least useful in resuming life as normal. In future disasters, we recommend the City of Boston dispatch mobile resources to those who are more reliant MBTA services. Among those surveyed, 42% of individuals needed access to grocery stores and 15% needed access to a doctor, yet these individuals had to wait for access until
transportation services were back online. It is our recommendation the City of Boston dispatch emergency food kits in vulnerable communities, as well as an on-call mobile medical unit for those who need immediate and urgent medical assistance. 

**FEMA:** In April 13th of 2015, FEMA announced funds would be made available to Massachusetts for the snowstorm that took place from January 26 through the 28th (FEMA 2015). A day following, this news drew sharp criticism from the Editorial Board of the Boston Globe and came as a disappointment to Governor Charlie Baker and the Massachusetts congressional delegation. While the snowstorm that took place between January 26 and 28th was declared a disaster, the Presidential declaration that awarded funds failed to capture the greater extent of the damage in the months of January and February of 2015. FEMA made eligible $67 million in funds, yet the extent of the damage from the relentless onslaught of storms and sub-zero temperatures is estimated to be near $400 million (The Boston Globe Editorial Board 2015). In future storms, we recommend a more holistic assessment damage to capture the full extent damage. 

**Finding 3: Communities with higher levels of participation felt that their communities were better prepared.**

We used our data to test how citizen involvement in the community interacted with belief about being ready for future crises. 

**Chart 2: Relationship between preparation and community voice**

<table>
<thead>
<tr>
<th>Scale</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>1.3</td>
<td>3.5</td>
<td>1.5</td>
<td>0.3</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>14.29</td>
<td>14.29</td>
<td>57.14</td>
<td>14.29</td>
<td>0.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Disagree</td>
<td>3</td>
<td>7</td>
<td>15</td>
<td>2</td>
<td>1</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>1.9</td>
<td>5.3</td>
<td>13.9</td>
<td>5.9</td>
<td>1.1</td>
<td>28.0</td>
</tr>
<tr>
<td></td>
<td>10.71</td>
<td>25.00</td>
<td>53.57</td>
<td>7.14</td>
<td>3.57</td>
<td>100.00</td>
</tr>
<tr>
<td>Undecided</td>
<td>2</td>
<td>6</td>
<td>17</td>
<td>10</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>2.3</td>
<td>6.7</td>
<td>17.3</td>
<td>7.3</td>
<td>1.3</td>
<td>35.0</td>
</tr>
<tr>
<td></td>
<td>5.71</td>
<td>17.14</td>
<td>48.57</td>
<td>28.57</td>
<td>0.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Agree</td>
<td>1</td>
<td>5</td>
<td>15</td>
<td>8</td>
<td>0</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>1.9</td>
<td>5.5</td>
<td>14.4</td>
<td>6.1</td>
<td>1.1</td>
<td>29.0</td>
</tr>
<tr>
<td></td>
<td>3.45</td>
<td>17.24</td>
<td>51.72</td>
<td>27.59</td>
<td>0.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Strongly Agree</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>1.1</td>
<td>3.0</td>
<td>1.3</td>
<td>0.2</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>0.00</td>
<td>16.67</td>
<td>16.67</td>
<td>16.67</td>
<td>50.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>
### Finding 4: Areas strongly affected by the MBTA suspension were already ones with weaker social ties and fewer existing safety nets – this was a doubly vulnerable population.

We began by mapping out the city of Boston using our social capital index. In the overall map of the city, seen in the upper left hand corner, it is possible to see comparative levels of social ties and cohesion, with red indicating high levels of connections and blue indicating low levels. The areas of Dorchester, Roxbury, and Mattapan were solid blues, indicating that we are very confident their levels of social capital and cohesion were demonstrably lower than other areas in the city, such as Brighton, West Roxbury and Somerville. Then, we plotted responses to our survey question, “My community is prepared for future disasters” in that area. This visual analysis is evidence that there are areas for growth in these communities. Only 25% of individuals surveyed responded either “Strongly Agree” (4%) or “Agree” (21%) to the prompt. The remaining 75 percent responded either “Undecided” (49%), “Disagree” (19%) and “Strongly Disagree” (7%).

**Figure 4: Levels of social capital and preparedness for future disasters**
Recommendations:
Local Communities and The City of Boston: Decision makers in Boston will need to address the challenges presented by low-social capital communities if it hopes to mount successful city-wide fronts to future natural and manmade disasters and confront increasing threats of climate change in its coastal communities. Policy makers should consider programs that have the potential to generate trust, norms of reciprocity and civic engagement. We recommend local community leaders and the City of Boston support the development of time banking and community-currency programs in Dorchester, Mattapan and Roxbury to increase social ties and deepen reservoirs of social capital.

Time banking programs, designed around social networks, have enabled community users to both offer and receive services that are assigned equal value. These programs have shown that the individuals who utilize this form of service exchange benefit from improved levels of social capital and health, especially among low-income individuals and those who live along (Lasker et al. 2011). Community currencies - forms of currency earned through volunteering or bartering in local communities - have been found to increase levels of generalized trust (Richey 2007). Recent studies have also found that intervention programs designed with goals of leadership
development (Brune and Bossert 2009) or microfinance and HIV education (Pronyk et al. 2008) have resulted in increased levels of social capital, despite the fact that these programs weren’t designed with those explicit goals.

Conclusions:
Using data from a variety of sources, including interviews, surveys, census data, and GIS data, we have sought to understand precisely how the massive snowfall in the winter of 2015 affected social systems in Boston. While outsiders may have been comfortable painting a broad picture of the city as “doing well” or “doing poorly” during the crisis, our data show that the effects of the storm were quite localized. Some residents were able to more or less carry on with their daily lives, yet vulnerable residents dependent on public transport found themselves unable to do so. These residents were also ones less likely to report their challenges to city authorities and ones who lived in less connected communities.

City level disaster managers and transportation engineers have to move beyond standard approaches during disasters where whole systems are optimized. This is because the actual on the ground effects of disasters vary from neighborhood to neighborhood, block to block. With social science data focusing on social capital and transportation hotspots, we can better direct resources to those with the most need. Further, reservoirs of social capital - the connections between local residents and their neighborhoods and between residents and their representatives and civil servants - are not set in stone. Instead, a wide variety of programs exist which can enhance and deepen these connections. Successful, tested programs include community currencies, time banking, better urban design, and community development. We want citizens to feel that they are taken seriously because such residents are the ones who feel best prepared for challenges like the 2015 Boston snowfall.

These results are not confined to Boston. Our analysis resonates with studies of other urban centers under stress which have similarly responded depending on levels of social resources (Klinenberg 2002; Aldrich 2012; Aldrich and Meyer 2015; Aldrich and Sawada 2016). Given the wide spectrum of hazards that cities will face, from rising tides to pandemics to heat waves, analysis of and investment in social resources remains a powerful way to mitigate risk. Residents who see themselves as integral to the community and participants in the decision makers are the best partners for building resilience.
ADDENDUM
HOUSEHOLD SURVEY

This questionnaire is designed to help policy makers understand households’ experiences of recovering from natural hazards and the factors that assisted in resuming life as normal after the 2015 Boston Snow Storms. The information you provide will help improve the response to future disasters. Please choose one adult member of your household over the age of 18 to complete this questionnaire on behalf of all family or household members. Your response to this survey will be kept confidential and anonymous. Thank you for taking the time to answer this questionnaire.

SECTION 1: HOUSEHOLD BACKGROUND QUESTIONS

1. Were you impacted by the 2015 Boston Snow Storms?
   □ Yes  □ No

2. Were you living in your current address at that time?
   □ Yes  □ No

3. Please give the address where you were residing at that time. If you don’t feel comfortable providing us with your address (which we’ll keep anonymous), we kindly ask for the nearest cross streets near your current address.

   Address: ________________________________________________________ OR

   Cross Streets: ________________________________ (Ex: Munroe St. and Harold St.)

4. Please give the number of people who were in your household at that time: _______ people

SECTION 2: THE IMPACT OF THE 2015 BOSTON SNOW STORMS

1. Please check all that apply: “As a result of the MBTA service suspensions during the 2015 snow storms, I …”
   □ Suffered wage losses □ Missed a scheduled hospital/doctor/dental appointment
   □ Missed work □ Missed school □ Experienced a negative health outcome

2. Please check all that apply: “As a result of the MBTA service suspensions during the 2015 snow storms, I needed, but had to wait for access to the…”
   □ Hospital □ Dentist □ Doctor □ Grocery store

SECTION 3: MY COMMUNITY AND THE 2015 BOSTON SNOW STORMS

1. “The City of Boston responded well to the 2015 snow storms”
   □ Strongly Agree □ Undecided □ Strongly Disagree
   □ Agree □ Disagree
2. “I felt the City did everything it could, within reason, to help my community resume life as normal after the snow storms.”
   - □ Strongly Agree
   - □ Undecided
   - □ Strongly Disagree
   - □ Agree
   - □ Disagree

3. Of the following, which resource proved MOST useful to you in resuming life as normal after the snow storms?
   - □ Immediate Family
   - □ Local Community Organizations (churches, clubs)
   - □ Neighbors
   - □ Close Friends
   - □ City Government
   - □ MBTA/Transit Company
   - □ Local Businesses

4. Of the following, which resource proved LEAST useful to you in resuming life as normal after the snow storms?
   - □ Immediate Family
   - □ Local Community Organizations (churches, clubs)
   - □ Neighbors
   - □ Close Friends
   - □ City Government
   - □ MBTA/Transit Company
   - □ Local Businesses

5. “My community bounced back quickly after the snow storms.”
   - □ Strongly Agree
   - □ Undecided
   - □ Strongly Disagree
   - □ Agree
   - □ Disagree

6. “My community is prepared for future disasters.”
   - □ Strongly Agree
   - □ Undecided
   - □ Strongly Disagree
   - □ Agree
   - □ Disagree

SECTION 4: NEIGHBORS AND COMMUNITY

1. “If I lost my job tomorrow, I would have friends or family to fall back on.”
   - □ Strongly Agree
   - □ Undecided
   - □ Strongly Disagree
   - □ Agree
   - □ Disagree

2. “In my community, my voice has an impact on the decisions that affect my neighborhood.”
   - □ Strongly Agree
   - □ Undecided
   - □ Strongly Disagree
   - □ Agree
   - □ Disagree

3. How many times a week do you go to your neighbors' homes or have them over to yours?
   - □ never
   - □ 1-2 times a week
   - □ 3-5 times a week
   - □ 5+ times a week

4. How often do you donate blood?
   - □ never
   - □ 1-2 times a year
   - □ 3-6 times a year
   - □ 7+ times a year

5. How often have members of your community come together to solve local problems?
   - □ never
   - □ 1-2 times a month
   - □ 3-4 times a month
   - □ 5+ times a month

6. Did you vote in the most recent election?
   - □ Yes
   - □ No
7. How often have you contacted elected representatives about issues of concern to you?  
☐ never  ☐ 1-2 times a year  ☐ 3-4 times a year  ☐ 5+ times a year

8. Have you attended a community event or meeting in the past month?  ☐ Yes  ☐ No

9. Have you helped a neighbor in the past month?  ☐ Yes  ☐ No

10. How much of the time do you think you can trust the government in Washington to do what is right?  
☐ Just about always  ☐ Most of the time  ☐ Only some of the time

11. How much do you agree with the following statements?  
(1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree)

<table>
<thead>
<tr>
<th>Statement</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>My neighbors will take advantage of me.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I trust my neighbors.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I trust my local government officials.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I have influence over making my place a better place to live.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>If something came up and I needed to go out, I could ask a neighbor for help in watching kids, etc.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most people can be trusted.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>My community feels like home.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>These days people need to look after themselves and not overly worry about others</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personally assisting people in crisis is very important to me.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

12. Do you or your family members participate in any groups or organizations? Examples could include religious, recreational, cultural, educational, neighborhood, and charities groups.

<table>
<thead>
<tr>
<th>Please spell out the name of the group or organization</th>
<th>How many hours a month do you participate in the group’s activities?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>_______ hours</td>
</tr>
<tr>
<td></td>
<td>_______ hours</td>
</tr>
<tr>
<td></td>
<td>_______ hours</td>
</tr>
</tbody>
</table>
SECTION 5: DEMOGRAPHICS

1. What is your age? ________________

2. What is your gender?  □ Female  □ Male

3. What is your race/ethnicity?
□ White  □ Black  □ American Indian/Alaska  □ Asian
□ Hispanic  □ American Indian or Alaska Native  □ Other ____________

4. Do you rent or own your home?  □ Rent  □ Own

5. How long have you lived in your current home?    _____  years

6. How long have you lived in this community?    _____  years

7. Please indicate your annual household income.
□ Less than $20,000  □ $20,001 --- $40,000  □ $40,001 --- $60,000
□ $60,001 --- $80,000  □ $80,001 --- $100,000  □ Over $100,001

8. Please indicate your level of education.
□ Some high school  □ College degree
□ High school graduate  □ Postgraduate degree
□ GED  □ Other ________________
□ Some college

9. Please indicate your religion.
□ Agnostic  □ Atheist  □ Buddhist  □ Christian  □ Hindu
□ Jewish  □ Muslim  □ Orthodox  □ Other: _________________

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**Bibliography**


GIS Sources

**Shapefile**

- Boston Neighborhoods
- MBTA “T” Points
- MBTA Bus Points

**Source**

- http://wsgw.mass.gov/data [Link]
- http://wsgw.mass.gov/data [Link]
- http://wsgw.mass.gov/data [Link]

**Other Data Sources**

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- Served on commit for local org (%)
- Engaged in fund-raising in /12 mos (%)
- Volunteered for a charitable org in /12 mos (%)
- Wrote or called a politician in /12 mos (%)
- Voted in federal/state/local election /12 mo (%)
- Attd Political rally/speech/org protest (%)
- Contributed to Political org in /12 mos (%)
- Contributed to religious org in /12 mos (%)
- Contributed to social services org in /12 mo (%)
- Contributed to health org in /12 mos (%)
- Contributed to educational org in /12 mos (%)
- Regional Snowfall Index

- https://bao.arcgis.com/
- https://bao.arcgis.com/
- https://bao.arcgis.com/
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- https://bao.arcgis.com/
- https://bao.arcgis.com/

**Links**

- http://gis.ncdc.noaa.gov [Link]
Appendix B

The Role of 311 Systems in Emergencies: Incorporating the Community into the Resilience of the Transportation System

Daniel O’Brien, Ph.D.

Boston is one of over 400 municipalities nationwide that have implemented a 311 system (or similar) that enable constituents to conveniently request government services. These systems typically comprise multiple channels, including a telephone hotline (3-1-1) and associated web apps and portals. Beyond giving the people of Boston more direct access to basic city services, 311 creates a collaborative process for the maintenance of the public spaces and infrastructure of the city, what we might call the *urban commons*. This becomes particularly apparent during weather emergencies. Whereas government agencies have the equipment, expertise, and authority to address failures of infrastructure, like impassable roads, broken signs, and downed trees, the public act as the “eyes and ears of the city,” alerting the government to such issues as they encounter them in their daily movements. In turn, the resilience of the transportation system in these times gains a behavioral component—it depends not only on the efforts of the government to maintain the roadways as passable, but also on the public’s proactiveness in reporting issues as they arise.

The collaborative nature of 311 was on display during Snowmagedon. The City of Boston received 44,576 requests for service during and immediately following the main snow storms, 81% of which (36,138) were requests for snow removal or plowing. As can be seen in Figure 1, such requests spiked on the days of major storms, but, especially following the later storms, continued for multiple days following the initial snow fall. This extended activity was instigated by the overall accumulation of snow. This corpus of information provides a digital artifact of the magnitude of the disruption Snowmagedon wrought on Boston’s transportation system, while also documenting the collaboration between the public and government services to address this disruption. However, to better understand where and how it was effective, this module will look at how engaged the public was neighborhood-by-neighborhood. Further, we want to go beyond mere description and determine the factors that predict this engagement, enabling governments who experience such events in the future to anticipate which neighborhoods will be most proactive, and which will need additional support in identifying and clearing blocked roadways or other storm-related failures in infrastructure.

*Requests for Snow Removal across Neighborhoods*
During the Snowmagedon period, Boston saw considerable variation in the volume of requests for snow removal across neighborhoods (approximated with census tracts), with some tracts producing very few requests \((min = 3)\) and others producing hundreds \((max = 584)\). The target area fell on the upper end of this distribution, with 70% of census tracts falling in the upper half of the distribution, and some sitting very close to the top. These raw counts are only so useful on their own, however. As we interpret variation in requests across the city, we must consider two questions. First, what does it mean for a community to be an effective collaborator in the maintenance of urban infrastructure? Second, what infrastructural features will directly influence the extent to which such effort is critical to the operation of that neighborhood? These two questions will determine how we organize the data and select our focal measures. Complete methodology for this and subsequent steps is available in Addendum A.

**Efficacy in Requesting Snow Removal**

At first glance, volume of requests for snow removal might be a reasonable indicator of how effectively a community contributed to the resilience of the local transportation system: it captures the energy within a community dedicated to this purpose. There is no guarantee, however, that this energy was comprehensive or that its distribution matched that of the neighborhood’s actual needs. Take the extreme example of a single resident who calls repeatedly about her unplowed street. Here, the volume is high, but only one street in a grid with many possible blockages has been flagged for snow removal. Less exaggerated examples might still alert city services to only a small proportion of streets in need of attention. Consequently, we need a more conclusive measure of how efficacious a community was in identifying and reporting locations requiring snow removal.

To address this problem, we assumed that every street has an even probability of requiring snow removal, and that deviations from this assumption constitute noise. By then aggregating from the street segment to the tract, approximately the same proportion of each tract’s street segments would require plowing. Based on this, a more effective measure of a community’s efficacy in supporting the resilience of the transportation system would be the proportion of street segments that generate requests for snow removal. If this number is low, it is presumed that the community’s participation in 311 is less effective at covering all issues needing attention, and if it is high, the community is notably vigilant. This measure is the basis of the proceeding analysis.

**Accounting for Local Infrastructure**

Towards the second question, some conditions will determine the extent to which a neighborhood will experience the disruption of the snow storm in such a way that will require snow removal. The simplest of these is the total length of roads—somewhat counter-intuitively, as the length of roads in a tract increased, the proportion of street segments reported went down, likely indicating a statistical balancing as there are more...
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roads (B = -.00001, p < .001). We then considered three additional factors, all of which had the predicted effects: the total length of dead ends, which often generate more requests as they are last on the plowing schedule (B = .00004, p < .001); the proportion of residents traveling by car, indicating a reliance on streets (B = .346, p < .001); and the proportion traveling by public transportation, also indicating a reliance on streets (B = .493, p < .001). Controlling for these items allowed us to more directly consider how effective each neighborhood was in its response to the storm, while taking into account infrastructural factors that might pre-determine the extent of this response. Complete model details are available in Addendum B.

**Explaining Efficacy in Requesting Snow Plows**

Figure 2 presents a map of the contribution of each census tract in Boston to the restoration of the local roadways, accounting for infrastructural variables that might pre-determine the extent of their need for snow removal (i.e., the residuals from the previously described regression). We see that most tracts in the focal area, highlighted on the map, had above-average efficacy in requesting snow plows, though a few were considerably below. Notably, these were largely white middle-class tracts (rather than the minority tracts that predominate in this region) and those tracts with public housing developments. A next and important step, highly useful to the management of future storms, is to examine which neighborhood characteristics actually help to explain and predict this variation in efficacy. This could be used to allocate resources to neighborhoods whose participation is low, which in turn might be suffering from critical street blockages that have not been reported. The first step is to examine demographic characteristics. We then look at how we might use 311 reporting over the previous year to increase our ability to identify neighborhoods with low participation in these regards.

**Demographics**

An initial model examined whether the age, ethnic composition, and affluence (i.e., median income) of a neighborhood influenced performance above and beyond the infrastructure (data drawn from the American Community Survey’s 2010-2014 estimates). Interestingly, we found that only the proportion of a neighborhood that was Black was a significant predictor, and this was positive (B = .19, p < .01), indicating that neighborhoods with a higher Black population made requests on a higher proportion of street segments, when controlling for infrastructural considerations. Though one might assume that disadvantaged neighborhoods would be less likely to engage in this way, this did not appear to be the case.

**Using Former 311 Usage to Predict Efficacy**
Using demographics to analyze the distribution of an outcome is a relatively simple and traditional test, common in the urban social sciences. It does not take advantage, however, of the richness of data available from modern administrative systems. If we are interested in how communities utilize the 311 system during a snow storm, we might be able to glean greater understanding from previous engagement with the same system. Because the vast majority of individuals use 311 only once in a given year or ever, the best way to generate a reliable prediction of future activity would be to tabulate those individuals who have used the system more than once in the previous year, indicating at least a moderate habit of participation. For this reason we created a measure of the proportion of each census tract’s residents who were “multiple reporters” for the year 2014 (see Addendum A for more detail).

The proportion of multiple reporters in a census tract positively predicted greater coverage of a neighborhood’s street segments, even when controlling for infrastructural and demographic factors ($B = .108$, $p < .001$). In fact, it explained over 10% of the remaining variation, demonstrating its strong explanatory value. Further, its inclusion altered the effect of demographic parameters in unexpected ways. It increased the effect of the proportion Black ($B = .232$, $p < .001$), and also revealed the proportion of people 18-34 as a significant predictor ($B = .211$, $p < .01$). This provides the additional insight that people in these two demographic categories utilized 311 to request snow removal at a level higher than would be expected by their regular usage of the system, possibly because they do not create registered accounts with 311 (making it impossible to track their individual usage over time), or because they are more attuned to the existence of the system and will engage with it during the special case of an emergency.

**Further Explorations: Social Media and Emergencies**

From this baseline, we might pursue various additional explorations. First, we can consider additional data sources that enable us to predict which neighborhoods need additional support in the identification and resolution of snow blockages. In this case, we look to the social media platform Twitter to identify other ways that individuals might communicate their frustration with a large snowfall and its consequences. Second, we might consider another manifestation of need visible in 311 data: requests for snow removal by emergency responders. These calls most often indicate locations where snow is impeding the ability of medical professionals to access or transport individuals requiring immediate attention.

**Twitter**

In recent years, Twitter and other social media platforms have become a popular venue for discussing pretty much everything, especially events that are collectively experienced, like extreme weather. During Snowmagedon 3,651 individuals made 5,749
tweets about snow that could be mapped to the city of Boston (with geotags, typically about 10% of all tweets; see Addendum A for more detail). Many of these tweets expressed frustration with the amount of snow and the difficulties it created, potentially reflecting energy that might be channeled more productively into requests for snow plowing via 311. We found that, controlling for all of the variables in the previous analyses, the number of Twitter users referencing snow in a census tract negatively predicted total coverage of streets (B = -.029, p < .05). Though the effect was somewhat modest, it did demonstrate that neighborhoods whose members are more active on Twitter during Snowmagedon were less efficacious in requesting snow plows. This would suggest that Twitter data might be utilized as an additional way for city services to identify areas that need support.

Emergency Responders

When the transportation system fails, a vital concern for residents is whether they will be able to access services in the case of a medical emergency. We see moments in which this worry becomes very real through 311 when emergency responders request snow plowing (as noted by a different case type). During Snowmagedon there were 559 such requests, with a greater density in some neighborhoods than others (requests per sq. miles of road ranging from 0 – 1.5). One will note from Figure 3 that tracts in our focal area were on the higher end of this distribution.

One theory would be that those neighborhoods with lower efficacy in requesting snow removal would be more likely to elicit such emergency calls. However, the correlation between their density and the coverage of streets was positive rather than negative (raw count of requests: r = .233, p < .01; controlling for infrastructure: r = .165, p < .05), indicating that neighborhoods that were more proactive in reporting snow blockages also had more emergency requests for snow removal. This uncovers an important caveat to the value of snow plow requests. A request for snow removal submitted through 311 is only the first step in a process. It must be received, entered into a queue, and then attended to in due course by a snow plow driver. It would thus seem possible that medical emergencies might still arise nearby a blocked street before a request for snow plowing has been addressed. As a result, community engagement with the maintenance of the transportation system may be only so helpful when the population itself is vulnerable to medical emergencies, as is true in disadvantaged areas like the one that was the focus of our study. In fact, it might be that this vulnerability stimulates more requests, but sometimes these requests are not addressed before a medical emergency arises.

Conclusions

This module has illustrated the role 311 systems play in creating a collaborative model for the resilience of the transportation system during a snow emergency, in which community members identify and report which areas city services should target with their snow removal efforts. This highlights the importance of community engagement with 311
as part of the overall response to this or any other weather-generated emergency. This engagement varies, however, across neighborhoods, and we see some lessons here in how cities might utilize this variation to best target their efforts.

- Neighborhoods that have a greater reliance on cars or public transportation are more proactive in reporting. Although we have treated this finding as an effort to control out infrastructural effects, it might mean that people who rely on these forms of transportation but live in neighborhoods where few others do suffer from uneven plowing.
- Demographic factors were only limitedly associated with participation, as Boston neighborhoods with higher Black populations showing greater street coverage. Affluence was not a factor.
- Cities can increase their ability to predict which neighborhoods will be most effective in identifying and reporting snow blockages by leveraging the data of the 311 system itself. The proportion of people in a census tract who had made two or more reports in the previous year was strongly, positively associated with participation.
- Whereas 311 captures active participation in this process, social media provides a window onto more passive frustration with snowfall. Neighborhoods with more Twitter users complaining about snow may be diffusing their energy around snow, requiring greater support from the government in identifying and addressing snow blockages.
- It should be kept in mind that even with active community guidance, snow plowing by city services is not a spontaneous process. As a result, problems around transportation access in the case of medical emergencies may still arise in the most engaged of neighborhoods, especially when the population is vulnerable to such events.
**Figure 1.** Number of Daily Snow Requests during Snowmagedon.
Figure 2. Efficacy in requesting snow removal across the tracts of Boston, accounting for key infrastructural variables.
Figure 3. Distribution of snow removal requests by emergency responders across tracts (per 1,000 m of road).
Addendum A. Methodology

This study utilized three main data sources: 1) 311 reports from the City of Boston; 2) population descriptors from the American Community Survey; and 3) geotagged tweets (i.e., posts to the social media platform Twitter). These data were provided in their curated form by the Boston Area Research Initiative (BARI), and the coordination of these data was facilitated by BARI's Geographical Infrastructure for the City of Boston (https://dataverse.harvard.edu/dataverse/geographical_infrastructure_2015), which maps all addresses in the city (based on the City of Boston’s Master Address List) to census TIGER line streets and geographies (e.g., census tracts). The Geographical Infrastructure supported measures regarding the number, types, and length of roads in census tracts as well.

311 Reports

Boston’s 311 system receives approximately 170,000 requests for service each year via hotline calls, an internet self-service portal, and a smartphone app (BOS:311, formerly Citizens Connect). Each case record includes the date of the request, the address or intersection where services are to be rendered, and a case type describing the nature of the services required. The place locations came from the City of Boston’s Master Address List, making it possible to map each to the containing road and census tract. The requests for service cover 228 different case types, 5 of which referenced snow removal: snow plowing, snow removal, city/state snow issues, snow/ice control, and snow plowing (emergency). The last of these was analyzed separately as it was generated by emergency responders, not community members. The database was shared by the Mayor’s Office and the director of the 311 system and curated by BARI (https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/CVKM87), and its use was approved by the Institutional Review Board.

Individuals can register with the 311 system, creating an account by which they can track their cases. Requests for service made through a registered account have a unique ID code that is appended to each of their reports, making it possible to create measures of each individual’s use of the system. Census tract of residence was determined directly for those whose account contained home address as part of the contact information (~45% of registered accounts). For the remainder, census tract was approximated as the tract where the individual most often made requests (a technique found to be accurate 94% of the time).

Main Measures

A neighborhood’s efficacy in reporting snow blockages was measured as the proportion of street segments in a neighborhood that generated at least one request for
snow removal during the Snowmageddon period (defined here as 1/24-2/22/15).

*Proportion of multiple reporters* was measured as the number of individuals residing in a neighborhood who made two or more requests for service during 2014, as a proportion of the total population.

**Population Characteristics**

The American Community Survey’s 2010-2014 estimates provided population descriptors for census tracts. These included measures of total population, ethnic composition (i.e., % Black, % Hispanic, % Asian), the representation of people 18-34, median income, and forms of transportation to work (% by car, % by public transportation).

**Tweets**

Tweepy, a Python package for accessing the Twitter API, was used to harvest all Twitter posts with geographical information (a setting within Twitter controlled by the user), from which the subset located within Boston were extracted (Wang and Taylor, 2015). In addition to the geographic location, the harvested metadata included the content of the tweet and the user ID of the individual who made it. We limited our analysis to all cases that included the word “snow.” We then created our main measure *Twitter users referencing snow* as the number of individual Twitter users who made at least one Tweet within a census tract regarding snow, divided by the total population.

**Analysis**

All measures were constructed at the census tract level and analyzed through multiple regression. There are 178 census tracts in Boston, but analysis limited to the 170 (5 tracts had a population of 0 and 3 had no information for demographic information). All data preparation, analysis, and visualization was conducted in R (Team, 2014).
Addendum B. Additional Statistical Tables

Table B1. Descriptive statistics for main variables

<table>
<thead>
<tr>
<th>Statistic</th>
<th>N</th>
<th>Mean</th>
<th>St. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of Streets with a Snow Report, 2015</td>
<td>170</td>
<td>0.387</td>
<td>0.174</td>
<td>0.007</td>
<td>0.862</td>
</tr>
<tr>
<td>Proportion of Multiple Reporters, 2014</td>
<td>170</td>
<td>0.019</td>
<td>0.013</td>
<td>0.001</td>
<td>0.150</td>
</tr>
<tr>
<td>Number of Individuals who Tweeted about Snow, Storm 2015</td>
<td>170</td>
<td>21.476</td>
<td>20.405</td>
<td>0</td>
<td>206</td>
</tr>
<tr>
<td>Proportion Age 18-34</td>
<td>170</td>
<td>0.394</td>
<td>0.184</td>
<td>0.000</td>
<td>0.965</td>
</tr>
<tr>
<td>Proportion Black</td>
<td>170</td>
<td>0.216</td>
<td>0.246</td>
<td>0.000</td>
<td>0.898</td>
</tr>
<tr>
<td>Proportion Hispanic</td>
<td>170</td>
<td>0.182</td>
<td>0.157</td>
<td>0.000</td>
<td>0.768</td>
</tr>
<tr>
<td>Proportion Asian</td>
<td>170</td>
<td>0.088</td>
<td>0.099</td>
<td>0.000</td>
<td>0.749</td>
</tr>
<tr>
<td>Median Household Income/1,000</td>
<td>170</td>
<td>58,052</td>
<td>30,950</td>
<td>12,813</td>
<td>180,417</td>
</tr>
<tr>
<td>Proportion Commuting by Car</td>
<td>170</td>
<td>0.462</td>
<td>0.191</td>
<td>0.003</td>
<td>1.000</td>
</tr>
<tr>
<td>Proportion Commuting by Public Transportation</td>
<td>170</td>
<td>0.331</td>
<td>0.126</td>
<td>0.000</td>
<td>0.746</td>
</tr>
<tr>
<td>Total Length of Dead Ends</td>
<td>170</td>
<td>3,887,376</td>
<td>2,503,168</td>
<td>18,280</td>
<td>12,585,960</td>
</tr>
<tr>
<td>Total Length of Roads</td>
<td>170</td>
<td>11,623,110</td>
<td>9,191,048</td>
<td>1,550,930</td>
<td>58,643,290</td>
</tr>
</tbody>
</table>
Table B2. Full results of regression models

| Dependent variable: Proportion of Streets with a Snow Report, Storm 2015 |
|------------------------------------------|----------|----------|----------|----------|
|                                        | Model 1  | Model 2  | Model 3  | Model 4  |
| log(Proportion of Multiple Reporters, 2015) | 0.108*** | 0.113*** | 0.113*** | 0.029*** |
| log(Number of Individuals who Tweeted about Snow + 1) | -0.009* | (0.015) | (0.015) | (0.015) |
| Age 18-34                               | 0.211**  | 0.221**  | 0.221**  | 0.221**  |
|                                       | (0.087)  | (0.087)  | (0.087)  | (0.087)  |
| Log(Black + 1)                          | 0.185**  | 0.183**  | 0.183**  | 0.183**  |
|                                       | (0.088)  | (0.088)  | (0.088)  | (0.088)  |
| Log(Hispanic + 1)                       | -0.189   | 0.035    | 0.035    | 0.035    |
|                                       | (0.121)  | (0.121)  | (0.121)  | (0.121)  |
| Log(Asian + 1)                          | -0.214   | -0.214   | -0.214   | -0.214   |
|                                       | (0.157)  | (0.157)  | (0.157)  | (0.157)  |
| ModHouseIncome (in Thousands)           | 0.004    | 0.004    | 0.004    | 0.004    |
|                                       | (0.001)  | (0.001)  | (0.001)  | (0.001)  |
| Commute by Car                          | 0.269*** | 0.257*** | 0.257*** | 0.257*** |
|                                       | (0.088)  | (0.088)  | (0.088)  | (0.088)  |
| Commute by Public-Transportation        | 0.697*** | 0.678*** | 0.678*** | 0.678*** |
|                                       | (0.057)  | (0.057)  | (0.057)  | (0.057)  |
| Total Length of Dead Ends               | 0.00000*** | 0.00000*** | 0.00000*** | 0.00000*** |
|                                       | (0.00000) | (0.00000) | (0.00000) | (0.00000) |
| Total Length of Roads                  | -0.00000*** | -0.00000*** | -0.00000*** | -0.00000*** |
|                                       | (0.00000) | (0.00000) | (0.00000) | (0.00000) |
| Constant                               | 0.157*** | 0.157*** | 0.157*** | 0.157*** |
|                                       | (0.010)  | (0.010)  | (0.010)  | (0.010)  |

Observations 170 170 170 170
R² 0.563 0.561 0.628 0.627
Adjusted R² 0.563 0.561 0.628 0.627
Residual Std. Error 0.124 (df = 165) 0.119 (df = 165) 0.109 (df = 159) 0.108 (df = 159)
F Statistic 42.110*** (df = 6, 165) 22.652*** (df = 6, 165) 26.662*** (df = 10, 159) 25.320*** (df = 11, 158)

Note: *p<0.1; **p<0.05; ***p<0.01

References
Acknowledgements

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We are grateful for the substantive contributions, hard work and supplemental reports, provided in Appendices A and B, written by Dr. Daniel Aldrich, Ms. Courtney Page, and Dr. Daniel O’Brien.

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Finally, our project and this report was only made possible thanks to extraordinary selflessness and professionalism of the many citizens, emergency responders, and local, state and federal officials who faced the daunting challenge of responding to and recovering from these historic snow storms and allowed us to learn from their experiences. In particular, we are grateful to the Massachusetts Emergency Management Agency and the Boston Mayor’s Office of Emergency Management for their professionalism and candor. We hope other communities are able to benefit from their experiences, and thank them and the entire City of Boston for allowing us to learn from them.
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