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Critical Path Method Assessment of Community Recovery

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Abstract

The critical path method (CPM) is investigated as a tool for identifying recovery activities that control the timeline for restoration of key community functions in the wake of a major disruptive event, such as a hurricane or tornado. Three recovery endpoints are studied: (1) restoring drinking water systems to normal operations, (2) returning children to school, and (3) returning businesses to normal operations. Interviews were conducted with individuals in seven communities who led recovery efforts between 2011 and 2019. The primary goal was to identify and document the sequence and duration of activities that would have delayed key recovery milestones if they had started later or taken longer to complete. Within each function, intermediate milestones are also identified, for example, students returning to school in temporary modules or the partial reopening of a business. Master tables for water, schools, and business are developed that summarize the activities on the critical paths identified in each community. Several opportunities to speed up the recovery process are identified, and issues relevant to the modeling of community recovery are discussed.

Key words

Business; Community Resilience; Critical Path; Flood; Hurricane; Recovery; School; Storm Surge; Tornado; Water.

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1. Introduction

Communities are encouraged to consider and plan for resilience to hazard events (hurricanes, tornadoes, flash floods, etc.). However, these same communities are often provided little guidance or do not have the tools at their disposal to inform their planning and decision making. In 2015, the National Institute of Standards and Technology (NIST) released the *Community Resilience Planning Guide for Buildings and Infrastructure Systems* [1] to help communities plan and implement measures for the built environment to strengthen their resilience to hazard events. NIST is also developing modeling tools to help communities understand and accelerate their recovery timelines under different hazardous event planning scenarios. This project addresses a key and poorly quantified aspect of resilience, the temporal aspects of a community's path to recovery following a major disruptive event.

This work focuses on the application of the critical path method (CPM) to the study of community recovery. CPM is typically concerned with project scheduling with an emphasis on the importance of scheduling dependencies. For example, in scheduling construction of a building, the start of some activities (e.g., installation of a roof) must wait on the completion of other activities (e.g., the framing of the building). CPM emphasizes understanding the important, or "critical", activities, those that, if delayed, would hold up completion of a project. Here, the CPM approach is applied to the analysis of community recovery from a hazard event. The goal is to understand recovery dependencies and to learn which activities, collectively referred to as the "critical path," are delaying the overall recovery timeline of a community.

There is value in identifying and understanding the commonalities in critical path activities across a variety of community and event types. First, to the extent that communities are facing similar delays, recommendations can be made to direct resources more effectively to speed up the recovery process. Second, this new understanding will help to inform modeling efforts at NIST. Greater modeling resources may be applied to more frequently encountered critical path activities.

A 2002 study by the Center for Risk Management of Engineering Systems [2] highlights the informational value of implementing CPM methods for disaster recovery. While limited to the transportation sector, the study makes clear that a comprehensive methodology is needed to apply CPM type analysis to the study of past events. Here an initial effort towards the development and testing of such a methodology is presented.

The newly developed CPM-motivated methodology was tested on seven communities that have experienced severe disruption from either hurricanes or tornadoes. They include Long Beach Township, NJ (2011 Hurricane Sandy); Monroe County, FL (2017 Hurricane Irma); Houston, TX (2017 Hurricane Harvey); Port Aransas, TX (2017 Hurricane Harvey); Tuscaloosa, AL (2011 tornado outbreak); Waterbury, VT (2011 Hurricane Irene); and the U.S. Virgin Islands (2017 Hurricanes Irma and Maria). The associated hazards include high winds, wind-driven rain, coastal storm surge, and riverine flooding.

Defining recovery is extremely challenging. For the purposes of exploring the applicability of the CPM method developed, we decided to limit our focus to the recovery of three particular social functions:

- Restoring drinking water systems to normal operations
- Returning children to school
- Returning businesses to normal operations

Recovery of these three social functions serves as a proxy for community recovery and return to pre-event or normal operations. It is important to acknowledge, however, that a fuller sense of community recovery extends well beyond restoration of just these three social functions. Also, it is important to note the difficulty in specifying meaningful operational definitions for the three social functions listed (e.g., all children return to school or 95% of children). The CPM approach addresses many such complexities.

This report is organized as follows. First, the methodology (Section 2) used to estimate the critical paths is described, with an overview of the major steps. Next, results (Section 3) are presented for the different case studies. The results are followed by a discussion (Section 4) and conclusions (Section 5). The appendices provide further detail on the results of the individual case studies and the research methodology.

2. Methodology

The project team began by conducting a review of more than 60 relevant publications. The team catalogued the literature into a sortable database by event type, whether the critical path to recovery was discussed, and by the social recovery endpoint. Some search terms included: “critical path,” “recovery,” “community recovery,” “milestone,” “school,” “business,” “flood,” “hurricane,” “tornado,” “potable water,” etc. The literature review indicated that CPM has not been widely studied with regard to disaster recovery. The majority of CPM studies touching on disaster recovery focused on the application of CPM to the scheduling of recovery activities for future or hypothetical events and not on analyzing recovery for past events. The literature review yielded few resources related to both the critical path methodology and disaster recovery steps. The literature review provided some insights on recovery milestones, recovery timelines, and personnel involved in the disaster recovery process. The project team used this information to help guide the semi-structured interviews.

Two approaches for gathering data on the timeline to recovery endpoints were noted in the literature: (1) survey mechanisms with random samples and (2) semi-structured interviews. Survey mechanisms are effective for gathering data related to the time to recovery endpoints or milestones but are less effective for mapping out the critical path to recovery. Given our limited understanding of the critical path to recovery, the project team concluded that a semi-structured interview approach would yield more details about the decision making process and the types of obstacles encountered on the path to recovery. The project team interviewed a convenience sample using existing personal and professional networks to select interviewees.

Our steps for designing, scheduling, and performing these semi-structured interviews are outlined below:

Step 1. Perform literature review: The project team performed a literature review to better understand: (a) previous efforts involving CPM in the context of disaster recovery, (b) typical steps and timelines for disaster recovery, and (c) to identify job positions (e.g., facility manager, superintendents, owner) involved in the recovery process for each social function (restoring water systems, returning children to school, and returning businesses to pre-event operations). The review also provided insights on individuals to reach out to for interviews and helped structure our field guides.

Step 2. Develop outreach method and field guides: The core of the outreach approach was to connect with a “point person” in the community to help us identify and connect with “key individuals” who were directly involved in the recovery process for each of the three social endpoints. The point person was often a community leader during the recovery period. In several cases, project team members had existing relationships from previous work in impacted areas, and these contacts either served as or connected us to a point person. The point person then connected us with key individuals from schools, water systems, and businesses who would ultimately be the interviewees. Appendix D provides the details of our outreach approach, and Appendices E-G present the field guides developed to guide our conversations with the key individuals about the critical path to recovery.

Step 3. Test the outreach method and field guides: The project team piloted the outreach approach and field guides in Long Beach Township, New Jersey. We had an existing relationship with a contact at the Jacques Cousteau National Estuarine Research Reserve who provided us a point person who served as the Sustainability Coordinator in Long Beach Township on Long Beach Island. The point person helped us set up meetings with the school district, water district, and a local business. This outreach process worked smoothly and was followed for the remainder of the project in six additional communities. Our testing revealed that the interviewees did not necessarily think about recovery in terms of a critical path, but rather as an event timeline, so we typically needed to do some interactive analysis with each interviewee to elicit and characterize the critical paths.

Based on the field guide test, we made an update to the approach that involves confirming critical steps by asking "if activity X had been delayed by a day, would the ultimate recovery time also have been delayed a day?" This additional question helped to confirm whether an activity was on the critical path as in some cases an activity might be, for example, of long duration and therefore memorable and yet not be on the critical path. Another lesson learned from the testing is that it is very helpful for interviewees to have a timeline (emails, journal, etc.) available of actions taken, so we could better develop a critical path that fit their timeline. Thus, we encouraged interviewees to bring along any notes, timelines, emails, calendars or documentation that would help them better identify the timing of events. Additionally, we made it a protocol to perform independent research (Facebook pages, web searches, Twitter, etc.) prior to meetings to help ground stories from the interviewee to specific dates.

Step 4. Obtain IRB approval and complete training: Team members involved in the interviews completed NIST human subject research training. After the field guides were tested, the project team worked with the NIST project manager to submit the field guides and training certificates to the NIST Institutional Review Board (IRB) and obtain IRB approval. The project team applied for an exemption as part of the application and IRB granted exempt status.

Step 5. Reach out to potential contacts and interviewees: After interviewing key individuals in Long Beach Township and obtaining IRB approval, subsequent interviews were arranged in six additional communities. The communities were selected to focus on relatively recent events in regions that had not already been selected for study under other NIST projects, which removed communities such as Joplin, Missouri (2011 tornado), Lumberton, North Carolina (2016 Hurricane Matthew and 2018 Hurricane Florence), and Puerto Rico (2017 Hurricane Maria) from consideration. We performed most of our outreach using existing points of contact as outlined in Step 2 above; however, for Tuscaloosa, a business in Houston, and the schools and a business in St. Thomas, we succeeded in arranging interviews with some cold calls and emails.

Step 6. Interview key personnel: The project team conducted interviews, each generally lasting 60 to 90 minutes, with key individuals across the three social functions, where applicable, in the following communities:

- Hurricane:
  - Monroe County, FL: 2017 Hurricane Irma (high winds, wind-driven rain, and storm surge)
  - Port Aransas, TX: 2017 Hurricane Harvey (high winds, wind-driven rain, and storm surge)
  - St. Thomas, USVI: 2017 Hurricanes Irma and Maria (high winds, wind-driven rain, and storm surge)
- Tropical or Post-Tropical Storm:
  - Long Beach Township, NJ: 2011 Post-tropical Cyclone Sandy, hereafter referred to more colloquially as "Hurricane Sandy" (storm surge)
  - Houston, TX: 2017 Tropical Storm Harvey, hereafter referred to more colloquially as "Hurricane Harvey" (wind-driven rain and inland flooding)
  - Waterbury, VT: 2011 Tropical Storm Irene, hereafter referred to more colloquially as "Hurricane Irene" (riverine flooding)
- Tornado:
  - Tuscaloosa, AL: 2011 tornado outbreak

Step 7. Document results: The primary goal for each interview was to identify and document the critical and near-critical activities on the path to recovery of a social function following a major disruptive event. With that goal in mind, the project team strove to keep the discussion focused on the sequence and duration of activities that would have delayed key recovery milestones had they started later or taken longer to complete (or, conversely, accelerated recovery had they started earlier or been completed faster). Due to the passage of time since the event, the various roles the interviewees in the recovery activities, and the complexity of the recovery activities, it was not always possible to elicit a complete set of activities and durations. In those cases, it was sometimes necessary to group related activities together or bound their durations as best as possible based on known dates.

Step 8. Analyze results by social function across events: Upon completing the interviews with key individuals in the seven selected communities, our next step was to organize and analyze the findings for each of the three selected social function across events. The goal of this step was to identify common recovery activities and milestones and understand the range of durations for each critical or near-critical activity.

Step 9. Identify implications and draw conclusions: Finally, we examined the study findings for actions that communities can take to speed recovery, and we considered the implications of the study findings with respect to the modeling of community resilience. We also assessed the research methodology and developed recommendations for its improvement.

3. Results

Presented below are critical paths for drinking water systems, schools, and businesses in each of the seven communities studied. For each social function (water, schools, business) being recovered, there may be one or more intermediate "recovery milestones" that precede "return to normal operations." For example, students returning to school in temporary modules or a business partially reopening may be recovery milestones. Some case studies contain multiple critical paths that overlap but end at different recovery milestones, such as a school reopening using temporary modules and then moving students from temporary modules back into normal classrooms. The water, schools, and business sections each have a master table summarizing the activities for all critical paths to recovery milestones that were identified in the event areas studied. In these master tables, blue shading represents a critical path activity and orange shading represents near-critical path activity (i.e., a step that was close to being on the critical path but ultimately was not).

3.1. Water

The project team conducted interviews with water district key personnel in six communities. Four of the six systems with whom the project team met had disruptions in service ranging from four (Monroe County) to about 56 (St. Thomas) days. We provide detailed case studies for each water system in Appendix A, including the sequence of each critical path for each disrupted water system.

Table 1 presents critical path activities for each of the four water systems that experienced a significant disruption of service. Following Table 1, we discuss the context of each of the major steps (grouped at a higher level) of the critical path activities in the table. Table 1 indicates which recovery activities were part of each critical path (blue shading indicates a critical path activity and orange shading indicates a near-critical path activity), the length of time each activity took, and the overall length of time to reach each milestone:

1) In Long Beach Township (LBT) for Hurricane Sandy (2012), we include critical path recovery activities for: (a) restoration of non-potable water service to the municipal building, which was the command center for the township's recovery effort; (b) restoration of non-potable water throughout all but the most southernmost section of the township (Holgate); (c) repair and re-pressurization of the Holgate section; and (d) removal of boil water advisories.
2) In Monroe County for Hurricane Irma (2017), we include critical path recovery activities for: (a) restoration of pressure in the main trunk line from the Florida City treatment plant in Miami-Dade County to Key West; (b) widespread restoration of non-potable water service; and (c) restoration of potable water service.
3) In Port Aransas for Hurricane Harvey (2017), we include the critical path to: (a) regain full water pressure with a boil advisory; (b) restoration of full water pressure with boil water advisory removed.

Table 1. Critical path activities and durations for water systems

	Long Beach Township Sandy Surge				Monroe County Irma Wind/Surge			Port Aransas Harvey Wind/Surge		USVI Irma/Maria Wind/Surge	
Critical Path Recovery Activity	**1a**	**1b**	**1c**	**1d**	**2a**	**2b**	**2c**	**3a**	**3b**	**4a**	**4b**
Time to Milestone	**4d**	**12d**	**~30d**	**~40d**	**4d**	**13d**	**15d**	**5d**	**14d**	**~40d**	**~56d**
Wait for access to water system											
Access (bridge insp. / debris removal)					1d						
Assess damage											
Perform damage assessment					2d	2d		2d			
Obtain outside assistance											
Request and receive outside assistance						1d-3d		1d			
Stabilize system											
Stabilize system					2d			2d			
Shut off natural gas	2d										
Bring in tanker trucks	2d										
Obtain generators, fuel, pumps											
Acquire portable diesel generator	2d							4d		40d	26d
Obtain & deliver backup generator fuel											
Other infrastructure repairs											
Electric power restored		NA									
Perform system repairs											
Temporary pump motors installed		NA									
Refill storage tank(s)	<1d	NA						<1d			
Repair broken water mains			NA								
Flush out lines		NA	NA					<1d		NA	NA
Flush out contaminated well											
Traffic delays after residents return						NA					
Restoration of service w/ boil water advisory						1d-8d		0d			
Restoration of outside water supply									10d		
St. Croix West end repairs and restoration											30d
Test water quality											
Water quality testing				NA			2d		2d		

4) In the US Virgin Islands (USVI) for Hurricanes Irma and Maria (2017), we present the critical path to: (a) restoration of service throughout St. Thomas and St. John; and (b) restoration of service throughout St. Croix.

The drinking water system in Tuscaloosa was affected by the 2011 tornado, but the damage was limited to a number of minor leaks that collectively caused the water levels in two storage tanks to drop. Within a period of two and a half days, the leaks were isolated and the water levels in the two storage tanks had returned to normal. Nonetheless, the City encouraged residents to restrict water usage and maintained a boil

water advisory for an additional three days. Based on input received from local officials, the project team decided against attempting to interview key personnel for the Tuscaloosa water system, opting instead to interview a second business. Similarly, neither Houston nor Waterbury experienced a loss of service, although, as noted below, both Houston and Waterbury did have changes and/or minor disruptions to their normal operations:

- In Houston for Hurricane Harvey (2017), drinking water service was maintained throughout the event. Much of the success was attributed to lessons learned and actions taken as a result of Hurricane Ike in 2008. There was some damage at the customer demand end where hoses to washers and refrigerators were broken and leaking. This led to some high bills for customers, which were forgiven by just charging customers at their 12-month average.
- In Waterbury for Hurricane Irene (2011), drinking water service was maintained throughout the event. Continuity of service was maintained due to the availability of two sources of raw water – surface water and deep rock wells. There was no damage to any water mains and pressure was maintained due to the presence of gravity flow throughout the system. Following Hurricane Irene, the town shut off its mountain stream intakes and switched to the wells. The wells gave the town time to clear debris from the surface water intakes and to let the turbidity of the surface water settle down.

3.1.1. Access facilities and assess damage

Access to system components to assess damage was an issue in LBT, Monroe County and the USVI, but it was only on the critical path in Monroe (1 day). Access in Port Aransas might have been an issue if all workers had evacuated.

Damage assessment was on the critical path for both Monroe and Port Aransas, lasting about two days in each case. In both cases, this step included waiting for evacuated personnel to get on site and delays due to difficulties in moving about the service areas. Access to facilities and damage assessment would have been on the critical path in the USVI had backup generators been in place at all of their pump stations.

3.1.2. Obtain outside assistance

Information collected during damage assessment phase provides a basis for activating mutual aid agreements and/or support contracts. Each of the four systems obtained outside assistance from contractors, through mutual aid agreements with other providers, or federal organizations (e.g., the US Army Corps of Engineers (USACE) in the case of the USVI). This assistance arrived within one to three days of being requested in Monroe County and within one day in Port Aransas. In most cases, outside assistance is used to repair distribution lines, allowing the system operators to focus on more fundamental issues involving water sources, treatment, storage and transmission through the main trunk lines.

In the USVI, outside assistance to St. Thomas and St. John following Hurricane Irma initially came from St. Croix and Puerto Rico, but those resources were lost when it became clear that those areas would be impacted by Hurricane Maria. After Irma and Maria, the USACE was critical in procuring and installing diesel generators at pumping stations in both the St. Thomas-St. John and St. Croix districts. These generators were

essential for restoring service throughout the two districts, particularly for customers at all but the lowest elevations.

3.1.3. Stabilize system

As damage is being assessed and outside assistance is being requested and organized, crews are working to stabilize the system and preserve treated water by shutting off valves to isolate segments that are leaking. This activity was on the critical path in Monroe County and Port Aransas, lasting about two days in each community. In areas where sand or other debris had accumulated, it took longer to locate valves, lengthening the duration of this activity. In LBT, backup generators fueled by natural gas initially kept the system under pressure, but pressure was lost when natural gas service to the entire area was shut off due to widespread leaks occurring at houses that had been displaced off their foundations by storm surge. In LBT and USVI, tanker trucks were used to distribute water to essential facilities, such as emergency operations centers and medical facilities.

3.1.4. Obtain generators, fuel, and/or pumps

In the USVI, obtaining and installing diesel generators at pump stations was, by far, the longest duration activity on the critical path to restoring water service to customers. Most pump stations in the USVI do not have a backup generator on site. Although the desalination plant in St. Thomas had only minor damage, it was unable to operate until the adjacent power plant was back in service (Day 7) and, even then, it was only able to serve customers at lower elevations in the area surrounding the plant. Customers at higher elevations and greater distances, including all of St. John, had to have potable water trucked in until the USACE was able to procure and install generators at each pump station.

In LBT, diesel generators had to be brought in when natural gas service was cut off. This activity took about two days, delaying both the refilling of water storage tanks and the process of identifying and repairing leaks in the system. In LBT, two of three pumps in Brant Beach were damaged by salt water inundation. They were replaced with temporary pumps for about one month while the original pumps were rewired and motors rewound.

3.1.5. Other infrastructure repairs

For the most part, damage to transportation, communication, and electric infrastructure did not directly impact the critical path. Instead, these disruptions tended to lengthen all of the other activities discussed in this section. One exception was LBT, where the restoration of service in the Brant Beach area was delayed by the combined loss of both electric power and natural gas service, as discussed above. The other major exception was in the USVI, where most pump stations did not have backup generators until they were procured and installed by the USACE and normal electric service was disrupted for several months.

3.1.6. Perform repairs

Repairs took between two days in Port Aransas and 40 days in the most heavily damaged section of LBT. In all four communities that experienced loss of water service, service was restored section-by-section.

Repairs included one or more of the following activities:

- Switching to alternate supply of raw or treated water if primary source is compromised;
- Flushing out contaminated wells;
- Repairing treatment facilities, if damaged;
- Adjusting treatment processes and re-supplying chemicals required to treat water;
- Replacing pumps damaged by salt water inundation;
- Refilling storage tanks; and
- Isolating and repairing leaks in the following order:
  - Mains
  - Distribution lines
  - Individual customers with significant leaks on their side of the meter.

3.1.7. Re-pressurize system section by section and restore service with boil water advisory

As sections of the distribution system are stabilized and repaired, those sections are recharged and flushed out by opening fire hydrants. If pressure can be maintained, the section can be reopened with a boil water advisory. This activity takes less than one day for each section.

3.1.8. Restore normal service (remove boil water advisories)

The final step is to take water quality samples and send them to a qualified laboratory for testing. This activity took two days in Monroe County and Port Aransas.

3.2. Schools

The project team conducted one school system interview in each of the seven study areas. We provide detailed case studies about each school system in Appendix B, including the sequence of each critical path for each school system.

Table 2 presents critical path activities for each of the school systems interviewed. Following Table 2, we discuss the context of each of the major steps (grouped at a higher level) of the critical path activities in the table. Table 2 indicates which recovery activities were part of each critical path (blue shading indicates a critical path activity and orange shading indicates a near-critical path activity), the length of time each activity took, and the length of time overall to reach each recovery milestone. The critical paths to recovery summarized in Table 2 are:

1) In Long Beach Township for Hurricane Sandy (2012), we include critical path recovery activities for the EJ School opening (1a), the EJ School opening with expanded modular space and more normal operations (1b), and the more heavily damaged LBI School opening (1c).
2) In Monroe County for Hurricane Irma (2017), we include critical path recovery activities for 15 of 16 schools opening (2a), Big Pine School opening with limited operations, with grades K-1 being moved to a nearby church and grades 2-5 being moved to the cafeteria (2b), and Big Pine School opening with more normal operations after repairs to the building (2c).
3) In Houston for Hurricane Harvey (2017), we include the critical path for 264 of 280 schools reopening (3a).

Table 2. Critical path activities and durations for schools

	Long Beach Township Sandy surge			Monroe County Irma wind/surge			Hous-ton Harvey rain	Port Aransas Harvey wind/surge			Tusca-loosa Tor-nado	Water-bury Irene rain	St. Thomas Irma wind/surge	
Critical Path Recovery Activity	**1a**	**1b**	**1c**	**2a**	**2b**	**2c**	**3a**	**4a**	**4b**	**4c**	**5a**	**6a**	**7a**	**7b**
Time to Milestone	**15d**	**6m**	**17m**	**16-23d**	**23d**	**7m**	**16d**	**53d**	**4.5m**	**12m**	**7d**	**10d**	**44d-62d**	**13m**
Wait for access to schools														
Wait for access to island	2d		2d					1d	1d	1d				
Wait for roads to be cleared											4d			
Wait for school to be done as shelter												1d		
Residents and staff return				<2d	<2d	<2d								
Assess damage														
Perform damage assessment	1d		1d	1.5d	1.5d	1.5d	1d	4d	4d	4d	<1d		NA	
Strategize and plan restoration														
Meet and decide when to reopen	<1d	60d	4m	<1d				3d			<2d	1d		
Decide whether to repair or rebuild						30d			<1d	<1d			NA	
Obtain financing														
Perform repairs														
Remediate schools									14d	42d				
Relocate boiler to higher elevation			>1yr											
Acquire and install water heater	<2d													
Perform general repairs	4d				13d	5m			111d	296d				
Perform infrastructure repairs														
Restore electricity	6d												NA	
Restore water				6d	6d	6d								
Restore internet														
Order and install temporary classrooms														
Order and install temporary classrooms		4m						40d						NA
Complete inspections														
Inspect portable units								1d						
Inspect indoor air quality							13d							
Communication and final preparations														
Prepare classrooms				2d				1d	5d	15d	<4d			
Rehearse modified bus routes				1d										
Communicate with students and parents	3d										3d			
Setup and organize volunteers												2d		
Confirm employees are able to return	<1d			<1d										
Allow time for families and staff to deal with issues at home				6d-13d										
Secure food supply														

4) In Port Aransas for Hurricane Harvey (2017), we include the critical path to all the schools opening with modular units (4a), the elementary and high school opening after repairs (4b), and the middle school and high school opening (4c).
5) In Tuscaloosa for the tornado outbreak of 2011, we present the critical path to the 850 displaced children returning to school at new locations (5a).
6) In Waterbury for Hurricane Irene (2011), we present the critical path to recovery to students returning to school (6a).
7) In St. Thomas for Hurricanes Irma and Maria (2017), we present the critical path to students returning to school on a shift-based schedule (7a) and the critical path for schools returning to normal schedules (7b). Due to extenuating circumstances, the project team was only able to gain a high-level understanding of the school recovery activities in St. Thomas. Thus, the individual critical path activity durations for St. Thomas are shown as not available ("NA") in Table 2, but overall durations are provided for the two milestones.

3.2.1. Wait for access to schools

Waiting for access took between one day in Waterbury and four days in Tuscaloosa. In Waterbury, there were no damages to the school; however, the town had to wait for the school's function as an emergency shelter to be completed. Accessing all 23 schools in Tuscaloosa was delayed four days due to debris in the roads. Access to schools on barrier islands took between one day in Port Aransas and two days in both LBT and the Florida Keys.

Access was quicker for schools on the barrier islands than for businesses because government officials were allowed back onto the islands before business owners and private citizens were permitted to return. Clearing debris and waiting for flood waters to recede was a near-critical path item in Houston.

3.2.2. Assess damage

Damage assessment took between about one day in Houston, LBT and Tuscaloosa and four days in Port Aransas. Typically, the damage assessment was dependent on the size of the school district, the event type, and the ability to communicate. For example, in Tuscaloosa, a relatively small part of the City was impacted by the tornado. Tuscaloosa City School officials were able to communicate quickly using LINK walkie-talkie phones, despite cell phones being out of service. School officials determined that only two schools (three buildings) out of 23 were significantly damaged by the tornado. Port Aransas had a pre-existing informal agreement with a disaster recovery and remediation contractor based in San Antonio to take the lead on restoring their schools. The contractor arrived on site on day three to perform the damage assessment. The time required for damage assessment in St. Thomas schools was not available.

3.2.3. Strategize and plan restoration

This group of critical path activities includes the high-level communication, strategy and planning activities taken by municipal and school officials. Across the seven study areas, these activities included:

- Communicate with students and parents about bus services and other logistics;
- Meet and decide when to open and announce reopening;

- Discuss damages and whether to replace/renovate or fix schools; and/or
- Obtain financing.

In LBT, it took schools a total of about 17 months to reopen fully, with several intermediate milestones along the way, such as opening the EJ School and expanding the EJ School's capacity with modular units. After Hurricane Sandy, it took less than a day for officials to meet, decide, and announce a target date to reopen the EJ School. This was very fast compared to the 60 days it took for officials to decide to expand the EJ School's capacity using modulars, and four months to determine a target date for a full reopening of LBT schools. Across the other study areas, it took between one and three days to meet, determine, and announce the target reopen date.

Another significant decision was whether to repair or rebuild schools. This took between one day in Port Aransas, TX and 30 days in Monroe County. St. Thomas schools had to determine which schools were repairable versus those that were completely destroyed. Financing almost slowed down the critical path to students returning to school in St. Thomas. Fortunately, however, many contractors agreed to work and defer payment to a future date.

3.2.4. Perform repairs

Repairs to damaged schools took between 4 days (LBT EJ School) and about one year (Port Aransas Middle School) across the school systems. This seemed to vary based on the extent of damage along with the pressure for schools to open. For school districts where students had suitable alternative options, the districts often took more time to make decisions and implement repairs. Common tasks within repairing schools include the following:

- Restore electricity: In Monroe County and LBT, crews restored electricity in about six days, which was part of the near-critical path. In St. Thomas, schools could not open until the US Army Corps of Engineers (USACE) was able to procure and install generators.
- Restore water: In Monroe County it took six days to restore water. This activity was neither a critical path nor a near-critical path activity for schools in any of the other study areas.
- Restore internet: Internet restoration was a near-critical path activity in Monroe County.
- Acquire and install water heater: In LBT it took just under two days to acquire and install a water heater, which was part of the near-critical path activities.
- Remediate schools: In Port Aransas, it took 14 days to remediate the elementary and high school and 42 days to remediate the middle school.
- Plan, engineer, and relocate boiler to higher elevation: It took over a year for LBT schools to plan, engineer, and relocate the LBI School's boiler to higher elevation; however, this was not a typical amount of time for that activity. A lack of urgency to reopen the school (because of other temporary options at another school) and some indecision about repairing vs. rebuilding slowed this step.
- Perform general repairs: This took between four (LBT) and 296 (Port Aransas) days. In Monroe County, it took a little over five months. This wide range

generally was driven by the extent of the general repairs needed and other external factors determining how quickly the school needed to be reopened. Basic repairs to St. Thomas schools were completed during the electricity restoration process.

Contractors completed general repairs at schools in a time period ranging from four days at the EJ School in LBT to 296 days at the Middle School in Port Aransas. It took 13 days for Big Pine School to reopen partially in Monroe County and five months for it to reopen at near normal operations. Finally, it took 111 days to open the elementary and high schools in Port Aransas. Tuscaloosa schools did not have a typical path to normal operations, and thus, the interviewees were unable to provide information that would have led to a critical path to normal operations. This was because there was enough extra capacity at the over 20 undamaged schools to comfortably accommodate the approximately 850 displaced students from the two damaged schools. This relieved any sense of pressure to rebuild or repair the damaged school buildings. As a result, the Tuscaloosa City School district used this as an opportunity to re-align the district and open an entirely new school, The Alberta School of Performing Arts, over 45 months after the tornado. This new school took the place of the former Alberta Elementary School.

3.2.5. Order and install temporary classrooms and complete inspections

LBT, Port Aransas, and USVI each ordered and installed portable modular units to be used as temporary classrooms. This took about four months in LBT and was intended to expand the capacity of a school that had already reopened. In Port Aransas, modular units were put into service as they became available. At 40 days, 75 percent of the modulars were installed, which was deemed enough to open school. The final 25 percent were installed during the first week school was opened back up. In St. Thomas, ordering and installing modular classroom units took several months and was not started until the school year ended (about eight months after Hurricanes Irma and Maria). Inspecting the portable units was only on the critical path in Port Aransas and took one day. Inspecting the indoor air quality of Houston's schools took 13 days prior to reopening. Due to the magnitude of flooding throughout the Houston region and the specialized nature of the services required, there was a shortage of qualified technicians for collecting and testing air quality samples.

3.2.6. Communications and final preparations

Communication and final preparatory activities included:

- Setup and organize volunteers;
- Confirm employees can return;
- Give time for families and staff to deal with issues at home;
- Secure food supply;
- Transport supplies and prepare classrooms (temporary or permanent);
- Rehearse modified bus routes; and/or
- Communicate with students and parents about bus routes and other logistics.

Setting up and organizing volunteers took two days (Waterbury) and confirming employees could return to work took less than one day (Monroe County and LBT). The

school system in Monroe County provided community and staff members between six and 13 (depending on school) days to deal with personal recovery issues prior to returning to school. Finally, communicating about and securing a food supply was nearly on the critical path in Houston, as refrigerated and frozen food at the schools had to be discarded. Houston schools would not have been able to open unless they could provide meals for its students. It took between one (modular units - Port Aransas) and 15 (middle school - Port Aransas) days to transport supplies and prepare classrooms. Transporting supplies and classroom set up was a near-critical path item in Monroe County (two days), LBT, and Tuscaloosa (less than four days). Rehearsal of new bus routes was a near-critical path item in Monroe County and St. Thomas, which took about one day. Finally, it took three days to communicate logistics to parents and students in LBT and Tuscaloosa. In heavily damaged sections of Tuscaloosa, teachers and school officials disseminated information to families via neighborhood "door knocking" teams.

3.3. Businesses

The project team conducted eight business interviews in the seven study areas (because the water system was not severely affected in Tuscaloosa, the project team opted to interview two businesses). We studied the critical paths for four restaurants, two independent hotels/resorts, one salon, and one brewery. We provide detailed case studies about each of these interviews in Appendix C, including the sequence of each critical path for each business.

Table 3 summarizes the critical path activities for each of the businesses we interviewed. This table primarily includes milestones to the businesses opening, and at the end of this section, we provide a subsection about the critical path to longer-term milestones such as reaching pre-event revenue. Following Table 3, we discuss the context of each of the major steps (grouped at a higher level) of the critical path activities in the table. Table 3 indicates which recovery activities were part of each critical path (blue shading indicates a critical path activity and orange shading indicates a near-critical path activity), the length of time each activity took, and the length of time overall to reach each milestone. We include the following critical paths to recovery:

1) In Long Beach Township (LBT) for Hurricane Sandy (2012), we include critical path recovery activities for a small restaurant to reopen after sustaining several feet of flood damage (1a).
2) In Monroe County for Hurricane Irma (2017), we include critical path recovery activities for a resort damaged by wind and storm surge to house displaced residents (2a), open to the public with a limited number of rooms (2b), and open the vast majority of the rooms (2c).
3) In Houston for Hurricane Harvey (2017), we include the critical path for (almost) reopening a large restaurant impacted by wind-driven rain (3a).
4) In Port Aransas for Hurricane Harvey (2017), we include the critical path for a small hotel opening to displaced residents after about 14 days (4a) and opening all 23 rooms to the public approximately 6 months later (4b).

Table 3. Critical path activities and durations for businesses

	LBT Sandy surge	Monroe County Irma wind/surge			Hous-ton Harvey rain	Port Aransas Harvey wind/surge		Tusca-loosa Tornado wind		Water-bury Irene flood		St. Thomas Irma wind
Critical Path Recovery Activity	**1a**	**2a**	**2b**	**2c**	**3a**	**4a**	**4b**	**5a**	**5b**	**6a**	**6b**	**7a**
Time to Milestone	**7.5m**	**22d**	**36d**	**96d**	**18.5m**	**14d**	**195d**	**12m**	**16m**	**6d**	**6d**	**110d**
Wait to gain access to business												
Wait for access to island	4d						3d					
Wait to learn about status of business			3d		2d							
Assess damage												
Assess damage					2d		2d	1d	<1d			
Cleanup and clear out debris												
Clean and clear debris	2d				14d		4d	9d	2d	2d		10d
Secure funding												
Wait for (private) funding/investment					30d							
Submit insurance information					12d		4d					
Wait for insurance payments					4m		1-2m	<90d	<90d			
Plan for rebuild and repairs												
Create rebuild/renovate strategy	3d			7d								
Cancel reservations to give guests more certainty			32d									
Perform infrastructure repairs												
Restore electricity		22d	22d	22d		10d						83d
Restore water						13d						
Perform repairs												
Repair/move electrical panels & restore power											4d	
Remove mold and demolish damaged buildings	21d											
Secure renovation team	4.5m											
Repair indoors	60d			60d	4m		6m	4m	3.5m			
Repair roof					60d		4m					
Repair equipment					6m							
Prepare/submit building permit package								51d	45d			
Iterate on planning issues to secure permit								20d	5.5m			
Prepare to reopen												
Restock supplies and equipment					21d		4d			<1 d		
Install equipment					2d							
Hire and train employees					14d							
Start brewing beer												16d
Restore cable/Internet				50d			24d					
Perform inspections												
Perform inspections					2d		1d	2d			<1d	
Miscellaneous												
Find new housing for displaced guests				5d			60d					
City imposes building moratorium								90d	90d			

5) In Tuscaloosa for the tornado outbreak of 2011, we present the critical path for a salon (5a) and a quick service restaurant (5b) reopening after being completely destroyed by a tornado.
6) In Waterbury for Hurricane Irene (2011), we present two parallel critical paths to a restaurant reopening after riverine flooding caused by a tropical cyclone (6a: debris removal and cleaning; 6b: electrical repairs).
7) In St. Thomas for Hurricanes Irma and Maria (2017), we include the critical path to a brewery (7a) reopening after waiting almost three months for the electricity to be restored.

Below, we provide additional context to support Table 3. This includes a discussion of common recovery actions that were on the critical path or near-critical path. We differentiate critical path and near-critical path activities in Table 3 as well as the individual case studies and network diagram tables; however, in the larger context below, we include a more integrated discussion of activities across all business regardless of whether they are critical or near-critical path.

3.3.1. Wait to gain access to business

Waiting to gain access took between two (Houston) and four (LBT) days. In St. Thomas, access was only delayed for a few hours for the business owners interviewed because their home had been completely destroyed and they needed to quickly determine whether they could temporarily reside at their place of business. Access was, generally, much more challenging and much slower for others on St. Thomas. It often took longer for people to access islands because government and municipal agencies restricted travel. This was the case in LBT following Hurricane Sandy, where emergency officials restricted access to the island for four days. Similarly, access to Monroe County and Port Aransas was restricted by emergency officials for three days following Hurricanes Irma and Harvey, respectively. Access was most often delayed by the need to clear the roads of debris or to allow flood waters to recede.

3.3.2. Conduct damage assessment

After accessing the business, most business owners conducted a damage assessment. This typically took one (Tuscaloosa) to two (Houston and Port Aransas) days. The time to perform this assessment did not vary much between businesses, and was typically done by the owner's own "eye test." In some places, like Tuscaloosa, the entire building was gone, which reduced the total time it took to go through the building and determine what was or was not damaged. Understanding the extent of the damages helped inform the planning stage of recovery. In Monroe County, the hotel did not have damage assessment on its critical path. However, it did take about 30 days to decide how far out to cancel reservations.

3.3.3. Cleanup and clear out business

Following a quick damage assessment, businesses often began cleaning out damaged equipment, securing contents that could be salvaged, and cleaning up the space. This took between two (LBT, Tuscaloosa, and Waterbury) and 14 days (Houston) depending on the extent of the damages. The cleanup process at the Houston restaurant was driven primarily by the time it took to disconnect and move the kitchen equipment, while juggling many other recovery activities, which included dealing with other businesses

they owned, assisting with community recovery activities, and attending to personal recovery activities. In the USVI, once power was restored, the cleanup process took 10 days. In Tuscaloosa, both businesses were able to leverage personal connections with contractors to quickly clear debris. This took between two (salon) and nine (restaurant) days. In Waterbury, many community members and volunteers from out of town helped clean out the business' storage room, which greatly expedited the cleanup process. In Port Aransas, the cleanup process took four days.

3.3.4. Obtain funds for repairs

Immediately following or parallel to the cleanup process, businesses often submitted insurance claims (it took about four days for Port Aransas business and 12 days for Houston business) and waited for insurance payments which took a little over a month for private flood insurance (Port Aransas), just over two months for insurance for wind damage (Port Aransas), and between (less than) 90 days (both Tuscaloosa businesses) to four months (Houston). In general, the businesses with the most catastrophic damage tended to have their claims settled the fastest, as there was little doubt as to the cause or magnitude of the damage. Conversely, businesses with serious but repairable damage tended to have longer insurance claims settlement times. Another important factor in the financing and speed of business recovery was whether the business owned the building or leased the building. Businesses that leased their buildings generally had more complex and more lengthy recoveries.

During the claims filing period, or soon after, businesses had to determine whether they had the financial capital to rebuild their business on their own, go through the FEMA assistance and/or the SBA loan application process, or secure private funding to fund repairs/reconstruction. Applying for FEMA assistance and/or SBA loans was described as labor intensive and confusing (LBT, USVI, Waterbury), and some businesses had trouble because they had lost (or never had) important documentation that was necessary to apply for grants or loans (Houston). Because of this, several businesses did not pursue these financing mechanisms and either personally funded repairs or used their businesses' line of credit for a loan from their bank (Tuscaloosa, USVI, Waterbury). One business (Houston) waited about 30 days for private investment to fund repairs. Uncertainty about funding was an issue for the restaurant in LBT, but it was neither a critical path nor a near-critical path item.

3.3.5. Plan for rebuild or repairs

Next, many businesses went through a period in which they had to decide whether to rebuild or repair and then plan out the process. This took between three days for the restaurant in LBT and seven days for the hotel in Monroe County. In both these cases, these decisions took a handful of days as owners had various conversations about the future of their business. In Monroe County, it took a little longer as they weighed the benefits and costs of accelerating substantial renovations that had already been in their long-term plans before the hurricane struck.

3.3.6. Perform repairs

This critical path category contains many components that vary greatly from one event area to another, as there are a number of outside factors that feed into this category. These activities include:

- Restore electricity;
- Restore water;
- Repair and move electrical panels and breakers out of basement;
- Demolish and remove water damaged items and remediate mold;
- Secure renovation team;
- Repair indoors;
- Repair roof;
- Repair equipment;
- Prepare/submit building and permit package; and
- Iterate on issues (building plans) before receiving permit.

At a high-level, the construction and repairs process took between three days for the restaurant in Waterbury to approximately 14 months for the restaurant in Houston. This wide margin is due to many factors that are briefly discussed, by location, below:

Long Beach Township (LBT): The critical path for the restaurant in LBT was driven largely by the time it took to secure a renovation team. After access to the island was granted, the restaurant attended community rebuilding meetings and completed demolition and remediation in under a month. It then took the restaurant approximately four and a half months to secure a renovation team, due to the lack of supply of trustworthy contractors, electricians, plumbers, etc. Hurricane Sandy struck in late October 2012, well after the end of the peak tourist season. What had seemed like plenty of time to reopen for the summer of 2013, became a rush to completion due to the long time required to find contractors. Fortunately, it took only two months to renovate the restaurant once the owners secured a team, and they were able to reopen just in time for the 2013 season.

Monroe County: The resort had 15 of 44 rooms that were undamaged and did not need any repairs. Repairs to the 29 damaged rooms took about two months, with no major obstacles, and the resort was able to open rooms on a rolling basis. Restoring electricity was an obstacle that took 22 days. About three months after Hurricane Irma, the resort was operating at near pre-storm capacity with 37 of 44 rooms opened.

Houston: After several slowdowns prior to performing repairs, the Houston restaurant's construction and repairs process was further slowed by unreliable contractors who did not perform the work they had promised, and low quality work that caused both new damage and a significant amount of repair work having to be redone. The repair process was also slowed down by waiting for funding or insurance money on multiple occasions. It took about four months to repair the restaurant, two months to repair the roof, and six months to repair equipment that sustained water damage due to faulty roof repair work. This damage was in addition to the equipment's initial damage.

Port Aransas: This process took about 6 months. The hotel fixed their 23 rooms on a rolling basis with two contractor teams. All rooms were inundated so the owners needed to replace the subfloor and sheetrock below four feet. The repairs generally went on without major issues, primarily due to the resourceful, motivated owners who were in good financial position prior to the event. The owners also maintained excellent business relationships with the contractors, both prior to and throughout their recovery.

Tuscaloosa: The two retail businesses in Tuscaloosa, AL (a salon and a quick service restaurant) had similar critical paths to recovery, largely due to the post-tornado steps taken by the city. Following the tornado, the City of Tuscaloosa initiated a 90-day building moratorium on new construction within the recovery zone (miscellaneous critical path item). This restricted any reconstruction activities, causing both the salon and the restaurant to have to simply sit and wait. During the 90-day building moratorium, the city took the opportunity to create Tuscaloosa Forward, a redevelopment plan to bring more businesses to the area. Following the building moratorium, the salon took approximately 50 days to prepare and submit a permit package, and another 20 days to go back and forth with the city on permitting issues. Contractors built the new salon building in four months with no major obstacles.

Following the building moratorium, the quick service restaurant spent approximately five and a half months going back-and-forth with the city about the Tuscaloosa Forward development plans and an egress point that the city wanted for a new commercial development immediately adjacent to their site. The egress point passed through the restaurant property and would have prevented the restaurant from rebuilding its drive through, a major part of the business. Following this back-and-forth with the city, the restaurant owner decided to hire a consulting firm to challenge newly updated flood maps, which would have required significant changes to the design and siting of their new building. This consulting firm's work successfully removed the restaurant (and several other businesses) from the flood zone. Once permitted, the new building was completed in about three and a half months with no major obstacles.

Waterbury: The Waterbury restaurant had the quickest recovery timeline observed by the project team. This was primarily because all restaurant operations were situated on the second floor of the building, outside of the flood area. The first floor, which was inundated with more than five feet of floodwater, was only a food storage and utilities area. The restaurant had two parallel critical paths, each with one repair activity. It took 4 days to repair/move electrical panels & breakers out of basement and turn on power and about a day to complete the inspection process. The restaurant reopened at normal capacity just six days after the flood.

St. Thomas: Many businesses in the USVI were completely decimated by Hurricanes Irma and Maria, necessitating complete rebuilds. This process is ongoing for many businesses; however, this was not the case for the small brewery studied. The building in which the brewery operates sustained minor roof cover damage, and there was no equipment damage. The primary obstacle to reopening was electricity restoration, which took 83 days. Hurricane Maria, which hit the USVI two weeks after Hurricane Irma, lengthened the electricity restoration process on St. Thomas. No other repairs were on the critical path.

3.3.7. Prepare to reopen

Preparing to reopen includes: (a) restocking supplies and equipment, which took less than one day for Waterbury, about four days to prepare rooms for the Hotel in Port Aransas, and 21 days for the restaurant in Houston; (b) installing equipment which took 2 days (Houston); (c) hiring and training employees which took 14 days (Houston); and/or (e) brewing new batches of beer, which took 16 days for the USVI brewery. Restoring cable

and internet was a near-critical path item in Monroe County, and took 50 days. This was not included as a critical repair to reopen, like electricity restoration, because it was not necessary to reopen. The resort reopened prior to restoration of internet and cable.

3.3.8. Complete inspections

After repairs, the typical final step was for inspectors to sign off on repairs and electrical work. This was typically a quick step at the end and did not add much time to the critical path, about one (Port Aransas and Waterbury) to two (Houston and Tuscaloosa) days. The Waterbury business owner noted that some other businesses needed to wait several days because there was a short supply of inspectors for electrical work; however, they were fortunate to have an inspector come on the same day they completed electrical work.

3.3.9. Critical path to long-term normal operations

The recovery activities above are focused on getting a business open; however, for some of these businesses, the critical path to normal operations (pre-hazard revenue or profit) took years. These critical paths were typically a completely different critical path (no overlapping activities) from those related to reopening the business and were mostly driven by how the surrounding community recovered. Additional details are provided below for businesses that reported having returned to normal operations:

- In Long Beach Township, it took the restaurant about two years to reach pre-event revenue and staffing levels, and another year to surpass pre-event revenue. The owners stated this was because the rest of the community had not been completely repaired, reducing staff availability and visitor traffic. The restaurant relies heavily on their summer, visitor-driven revenue, which was unable to rebound until the rest of the community recovered and tourism returned to normal.
- In Monroe County, the hotel was operating “very close” to normal capacity approximately 10 months after the event. As in LBT, the Florida hotel’s ability to achieve “very close” to normal operations was heavily dependent on the recovery of the surrounding community, which would speed up the return of tourism. For example, there were some surrounding marinas that the hurricane destroyed and had not been rebuilt, limiting the ability for recreational fishing boats to get fuel, which is an important activity for guests.
- In Waterbury, the business took about four years to reach pre-event revenue. This is because 1,500 state workers were relocated for four years, and many workers from another major employer had left the area after the flood. Once the state employees returned, the restaurant was able to rebrand and return to close to normal operations.
- In Tuscaloosa, both the salon and the quick service restaurant surpassed pre-tornado revenues in the year following the tornado. This was largely because much of the city did not experience any damage from the tornado, enabling much of the community to return to normal operations immediately after the tornado.
- In St. Thomas, it has taken the brewery about 18 months to reach “very close” to pre-hurricane revenues. This is in part due to expanded capacity, but is primarily due to the recovery of the surrounding community, which is slowly allowing the tourism industry to recover.

4. Discussion

In reviewing the results across communities, hazards, and social functions, several themes emerged. Below, we discuss the support that the results offer for taking various actions to speed up recovery, the implications of the study findings with respect to community resilience modeling, and potential improvements to the research methodology.

4.1. Actions to Speed Up Recovery

There are many actions that communities can take to increase their resilience, and the results of this study lend direct support to several. While a greater number of communities and hazard types, and consideration of costs, are needed to more fully validate the merits of these actions, all should be considered:

Develop relationships or formalize agreements with general contractors, electricians, plumbers, and other specialty recovery services before the event to secure these valuable resources (Schools, Businesses). Schools that had established formal or informal contracts with these valuable service providers began the recovery process immediately. To maintain these relationships, it is important to be in a position to pay providers promptly. Similarly, business owners with personal or existing professional relationships with contractors were typically able to secure renovation teams and start the restoration process much sooner than businesses that did not have these relationships. Both businesses studied in Tuscaloosa were able to secure contractors and start their recovery process immediately, whereas the business studied in LBT spent an extended period securing a renovation team.

Ensure immediate access to funds and maintain relationships to obtain lines of credit quickly (Schools, Businesses). It often took months for insurance, SBA loans, or other public assistance funds to be paid out. To speed up the path to recovery, many schools and businesses found having access to funds to pay contractors immediately was key to starting the recovery process. For example, Tuscaloosa City Schools did not wait for financial assistance from FEMA. Instead, the district had the resources to proceed with their recovery efforts on their own and then later obtained reimbursement from FEMA. The owner of the flooded Waterbury restaurant indicated that he was able to get loans very quickly from his bank using his line of credit and from the Vermont Economic Development Authority (VEDA). He did not want to incur delays going through other loan or grant application processes, such as FEMA or the Small Business Administration (SBA). In Port Aransas, the hotel owners noted the importance of having several months of operating revenue on hand to start the recovery process promptly.

Maintain accurate records of shut-off valve coordinates to help limit water losses and facilitate recovery (Water). Many events required shutting valves off across the affected area to limit water losses and maintain pressure, and this task was often performed by water utility staff from other communities who were called in for emergency assistance, typically via mutual aid agreements. Contacts from Monroe County, Port Aransas, and Waterbury mentioned that this task would have been aided by accurate and easy-to-access records of valve coordinates. Major events can generate

significant quantities of debris and destroy or move landmarks, making it hard to locate shut-off valves. Modern geographic information systems (GIS) would enable workers to find valves quicker, speeding up damage assessments and repairs.

In areas where power may be disrupted for extended periods, ensure generators or other sources of backup power are available (Business, Water, Schools). While electricity restoration was not a critical path activity in most of the communities studied, the lack of electricity did often slow other steps down. For water, getting the power back on would have been part of the critical path in more cases if backup generators had not been in place prior to their event. In the USVI, normal electric service was disrupted for several weeks or more and all three social endpoints would have benefited from earlier availability of generators. The USVI Water and Power Authority (WAPA) depended on the USACE to install generators at critical pump stations. Similarly, the USVI school system was delayed in performing repairs until the USACE completed the installation of generators. Students were able to return to school, on a shift-based schedule, after the installation of generators. The USVI brewery did not have access to a generator, and had to wait until power was restored in late November (83 days after landfall) to properly clean their equipment and begin preparations for reopening. Regardless of the system (business, water, or schools), the availability of electricity is important, and access to or owning a generator can greatly speed up the path to recovery.

Attain consensus on mid- and long-term plans before a major disruptive event occurs (Schools, Businesses). After an event, there are many decisions to be made; however, this is a very difficult time for a school district or business to initiate and sustain a proper long-range planning process due to the urgency to rebuild and the need for community members and employees to deal with their own family-related recovery issues. Some of the school systems and businesses interviewed wished they had had mid- and long-range plans in place prior to their event (e.g., should they repair, replace, relocate, consolidate, or expand?). Some school districts and businesses, such as the Middle School in Port Aransas, had these plans in place and therefore were able to start their renovations or rebuilds right away. Tuscaloosa City Schools had extra capacity in their system, which enabled them to relocate about 850 impacted students to other schools within their district and allowed their planning and rebuilding process to proceed at a relatively normal and unhurried pace.

Exercise caution when piling and collecting debris (Water). In areas with heavy damage, home and business owners quickly began piling debris along streets, making it difficult to locate water shut-off valves (Monroe County, Port Aransas, Waterbury). In addition, front end loaders damaged valves or meters when collecting debris, creating new leaks and localized losses of service for weeks after the event (also Monroe County, Port Aransas, Waterbury).

Increase of understanding of how FEMA assistance programs work and lessen effort required to apply for assistance (Businesses, Water, Schools). For businesses, in particular, there was some confusion about how the FEMA process worked and for what situations FEMA would provide assistance (LBT, St. Thomas, Tuscaloosa, Waterbury). This led to situations where businesses, in particular, were unsure of whether to wait or move forward. Schools and water systems (and in some cases businesses), just

moved forward without waiting for FEMA because they had to open promptly (Tuscaloosa, St. Thomas, and Waterbury). While this issue was not part of the critical path in most cases, it diverted attention from other critical path steps and may have slowed down those steps.

4.2. Implications for Community Resilience Planning and Modeling

The results also suggest the importance of addressing certain items in community resilience planning and modeling. For example, modeling of complex regional systems, such as transportation, communications, and electric power, could be accomplished through the use of modifiers to the duration times of other activities or through explicit modeling of the separate systems and their interdependencies. Another important consideration is the distinction between near-term community recovery, which may be more dependent upon physical damage and restoration, and long-term recovery, which may be more dependent upon social and economic issues. Not surprisingly, resource availability also played a big part of the critical path. Modeling the critical path should account for these resource limitations, especially skilled trades. These and other issues are further discussed below.

The state of transportation, communication, and electric power networks can affect recovery activity durations. Transportation issues, loss of communications, and/or loss of electricity extended the recovery timeline in almost every case study. Restoration of these three networked systems were sometimes elicited as part of the critical path but were more often cited as obstacles that extended the duration of other recovery activities. For example, transportation issues may not prevent a preliminary assessment, but they often increased the time it took to get started and complete (Monroe County, Port Aransas, and St. Thomas). The lack of communication (i.e., internet and phone), may not have prevented another recovery step from occurring, but it may have required people to travel at length to meet in person and thereby slow down decision making (Monroe County and St. Thomas). It took more than five days for communications on St. Thomas to improve. Many hours were spent during that period searching for locations with adequate cell phone service. Similarly, people could often make some repairs without electricity, but these may be slowed down because of a limited number of generators, or their work might be limited to daylight hours. While restoration of these systems were only sometimes a step on the critical path to recovery, they often influenced the overall time to recovery, which will be important to consider in modeling.

Modeling attainment of long-term recovery requires broader social and economic modeling. Businesses may not fully return to normal pre-event revenue, schools may fully return to normal enrollment, and water systems may not return to normal pre-event demand until the residential and business sectors have recovered and residents, employees, and visitors have returned to the community. In contrast, getting to a minimal or partial level of recovery may simply involve enough restoration of utilities and enough basic repairs to reopen a business at reduced hours or a reduced capacity. Thus, we often observed significant differences in the critical paths for longer-term versus shorter-term milestones (LBT, Monroe County, Port Aransas, Waterbury, St. Thomas).

More complete recovery of a business is dependent on the recovery of the local economy. The critical path to return to pre-event revenue for businesses was often

dependent on the recovery of the surrounding community and economy. Businesses interviewed in LBT, Monroe County, Waterbury, and St. Thomas indicated they were able to re-open prior to the recovery of the surrounding economy; however, their return to "normal" revenue was tied to the timeline of the community returning to normal operations. This was especially true for businesses located in tourism-dependent communities and economies, including Monroe County, LBT, and Port Aransas.

Resource availability may be a significant factor in recovery times. Absent a hazard event, a recovery activity may only take a day or two to complete. However, post-event it may take much longer because of the limited availability of resources required. Modeling of recovery should account for the impact of resource limitations on recovery times. This impact was observed in several case studies:

- **Skilled trades, including electricians, plumbers, carpenters, and inspectors.** Many businesses had trouble finding contractors (this took over four months in LBT) or found very expensive or unreliable contractors (who left or did poor work). This was the case in Houston, where unreliable contractors with erratic schedules extended the repair process and some of the repairs were done poorly, resulting in additional damages. For the Houston schools, there were a limited number of trained inspectors to deal with the nearly 200 schools that needed air quality testing. For some businesses (Waterbury), there were a limited number of electric inspectors available to approve restoration of connections to the power grid.
- **Housing.** For islands, a lack of places for recovery teams to stay slowed the recovery process. In Monroe County and Port Aransas, there were not enough places within or near the affected areas for contractors and recovery teams to stay in many cases. Recovery teams often needed to bring everything (RVs, food, generators, etc.) in order to avoid long commutes in and out each day. In the USVI, there were some livable hotels on St. Thomas that housed many of the emergency workers, despite not having internet or electricity. A cruise ship was also brought into port to provide living space.
- **Materials.** St. Thomas, an island with no access by ground, relies on imports for nearly all materials. Imports were delayed due to a combination of issues, including port access, the large quantities of materials needed, and the fact that many other Caribbean islands needed similar materials following Hurricanes Irma and Maria.

Grassroots organizations can play a key role in the recovery process. In Waterbury, LBT, and Port Aransas, various organizations stepped up to provide support to businesses. Some of these organizations provided meals for recovery workers and business owners so they could focus on recovery, others organized volunteers to help with cleanup tasks, and some provided guidance on the overall process, including providing access to much needed contractors. Some of these organizations were spinoffs of existing organizations and relationships, but it seemed these were more prevalent in the smaller, tighter-knit communities. For example, Rebuild Waterbury (RW) was a recovery-focused spin-off of an existing community development group, Revitalize Waterbury. RW worked to organize volunteers, raise money for local businesses and

homeowners, and connect people to speed up the recovery process. In Port Aransas, an impromptu "Cowboy Camp David" provided food to recovery workers and business owners, allowing them to focus on recovery activities. For resilience modeling, metrics or indicators of the degree of social connectedness within the community could serve as proxies for the likelihood that grassroots organizations will form to help accelerate the recovery timeline.

Water, schools, and business represent three major phases of overall community recovery. Water recovery represents a major milestone in overall community recovery by fulfilling a basic need. In some cases, residents were not allowed back to their homes until the community could restore water service. Getting students back to school was often described to the project team as a major morale boost for the community as it allowed students to start to have a semblance of a normal day and allowed parents of the students to focus on residential and business recovery activities. When businesses opened, community contacts described an increased feeling of normalcy. Achieving pre-event revenue for businesses often was an indicator of more complete community recovery as this typically relied on people fixing their residence and moving back, and all other businesses recovering to effectively attract tourists to the area (in tourism areas).

4.3. Assessment of the Methodology and Recommendations for Improvement

Lastly, we discuss the strengths and limitations of the research methodology and provide recommendations for improvement:

Notecards were typically useful: As described in the field guides (Appendices E-G), notecards representing recovery activities were used in a graphical elicitation of the critical path from the interviewees. The cards were helpful for the interviewers, but some interviewees were more difficult to reign in and less methodical in presenting the timeline. The notecards helped us keep the focus on the critical path activities.

Performing interviews in-person: Preliminary conversations were held with most key personnel on the phone prior to the in-person meeting to discuss logistics and determine whether the case study was appropriate for our project. Interviewees opened up substantially more in-person compared to on the phone, and the travel helped them see this as a serious effort. Finally, we did hold one phone conversation because the interviewee had to postpone due to illness. It was quite a bit more challenging to guide the follow-up phone conversation, partly because we were unable to show the interviewee the critical path to recovery using notecards.

Finding a point person to introduce us to key personnel for interviews: Multiple interviewees told us that the primary reason they spoke with us was because of the recommendation from the point person, and one key individual specifically told us we would not have been offered a meeting without being recommended by the point person. All of the interviewees volunteered their time. These key individuals have generally been inundated with requests for their time over the years, so having a recommendation to validate our effort was extremely important in successfully setting up interviews. For Tuscaloosa, St. Thomas, and a business in Houston, we needed to send cold emails and make cold calls in order to get interviews. This process was substantially more resource intensive, but ultimately worked out with some persistence.

Using two people at interviews: We generally had one person lead the interview and take light notes and the second person develop the critical path on note cards. We would have missed more details with one person, and it would have been challenging to frame the conversation in the context of the critical path without this second person filling out the notecards outlining the critical path.

Timing of event has a big impact on data quality: The interview process seemed to work best for events within the past two years when studying the disaster recovery process for most milestones. Understandably, interviewees struggled to remember the sequences and durations of events and the dependencies between events that occurred several years ago, especially if they did not have an internal report or contemporaneous notes, such as emails, social media postings, or press releases, to refresh their recollections. Although it often took longer than two years to achieve some longer-term milestones, such as returning to pre-event revenue for businesses, these critical paths were often simpler and more dependent upon the recovery of the community as a whole.

Some information may be collectable via survey: Most interviewees were unfamiliar with the critical path concept. Therefore, it would likely be overly challenging for a survey mechanism to collect the actual sequence of events for a critical path. However, a survey could:

- Provide a list of recovery activities and ask respondents to select all that apply (at this point this list would include both critical and non-critical paths).
- Ask respondents the order and the length of time for each recovery activity (at this point this list would still include both critical and non-critical paths).
- Ask respondents to select from their list of recovery activities, which ones if delayed by one day would have delayed the date of a recovery milestone by a day (this will help differentiate those on the critical path from those not on the critical path).

Additional hazard types: The communities visited in this study were impacted by high wind events (hurricane or tornado) and/or flood events (coastal or inland). Additional research is needed in communities impacted by earthquakes, wildfires and other hazards to understand the extent to which the critical path to recovery depends on the type of hazard.

Additional endpoints: The community functions of water, schools and business were the focus of this study. Other endpoints should also be investigated, such as restoration of housing and recovery of community culture and identity.

5. Summary and Conclusion

The critical path method (CPM) is a useful tool for identifying those recovery activities that control the timeline for restoration of key community functions in the wake of a major disruptive event, such as a hurricane, flood, tornado, earthquake, or wildfire. To explore the applicability of the CPM methodology to community resilience modeling, the recovery of three social functions of a community have been studied:

- Restoring drinking water systems to normal operations
- Returning children to school
- Returning businesses to normal operations

Interviews were conducted with individuals in seven communities who led recovery efforts between 2011 and 2019. The primary goal was to identify and document the sequence and duration of activities that would have delayed key recovery milestones if they had started later or taken longer to complete (or, conversely, accelerated recovery if they could have been started earlier or completed faster). Within each function, some intermediate milestones have also been identified, for example, students returning to school in temporary modules or the partial reopening of a business. Master tables for water, schools, and business have been developed that summarize the activities on the critical paths identified in each community.

Long-term endpoints and short-term endpoints often followed different critical paths. Short-term endpoints often included a water utility restoring service with a boil water advisory, getting students back to school in temporary classrooms, or reopening a business at reduced capacity. These critical paths typically involved shorter term activities such as cleaning up, assessing damage, obtaining financing, performing repairs, and completing inspections. The long-term endpoints typically included returning to normal water demand and revenue, returning to permanent classrooms and normal enrollment, or returning a business back to its pre-event revenue levels. For retail businesses, in particular, the long-term recovery paths were often quite dependent on the rest of the area completely recovering, including the residential sector. As residents move back to the area, the employee and client base returns, and tourists return (if applicable), so could the normal operations of these three social endpoints.

Several opportunities to speed up the recovery process were identified. These include increasing the availability and accuracy of community-scale data (e.g., water shut-off valve coordinates), improving pre-event planning in ways that will accelerate recovery, and strengthening relationships that will prove helpful for recovery. These observations are consistent with guidance provided in the NIST Community Resilience Planning Guide.

The findings will also help inform community resilience modeling efforts. For example, the results suggest that it may be more practical to model the effects of short-term disruptions to regional infrastructure services (e.g., transportation, communications, and electric power) with modifiers to the duration times of other activities rather than attempting to explicitly model these systems and their interdependencies. Likewise, resource constraints (e.g., skilled trades, recovery worker housing, and materials) can also

play a significant, but difficult to explicitly model, role in the first few days and weeks of recovery. At the other end of the spectrum, the findings suggest that economic and social modeling should be primary points of emphasis for modeling long-term community recovery.

Future research should focus on obtaining more statistically significant data on the length of critical recovery activities across a broader range of events and recovery endpoints. Based on lessons learned from this research, it seems as though it would be a challenge for respondents to outline critical path via a survey mechanism; however, respondents would likely be able to identify recovery activities from a list, indicate the length of time the activity took for their event, and perhaps indicate whether overall recovery timeline would have been delayed if the duration of the activity had been increased by one day.

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The views expressed in this report and any errors are the responsibility of the authors.

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Appendix A: Water System Critical Path Case Studies

- A-1: Long Beach Township, NJ (Hurricane Irma, 2017): Water Systems
- A-2: Monroe County, FL (Hurricane Irma, 2017): Water Systems
- A-3: Houston, TX (Hurricane Harvey, 2017): Water Systems
- A-4: Port Aransas, TX (Hurricane Harvey, 2017): Water Systems
- A-5: St. Thomas, USVI (Hurricanes Irma and Maria, 2017): Water Systems
- A-6: Waterbury, VT (Hurricane Irene, 2011): Water Systems

A-1: Water Supply System Recovery in Long Beach Township, NJ (Hurricane Sandy)

Water System Information

- **Employees (2012):** 10 full-time, 2 part-time, plus contractors
- **2010 Population**: 3,051
- **Critical customer(s):** LBT Municipal Building
- **Sections and Damage**:

Section	Water Source	Damage
High Bar Harbor	Water purchased from Barnegat Light	No damage
Loveladies North	Water purchased from Barnegat Light	No damage
Loveladies South	Water purchased from Harvey Cedars	No damage
North Beach	Water purchased from Surf City	No damage
Brant Beach	3 treatment plants and storage tanks operated by LBT	Well #3 contaminated by salt water
	➢ 58th Street	Pump motor flooded
	➢ Peahala Park	No significant damage
	➢ Beach Haven Terrace	Pump motor flooded
Holgate	1 treatment plants and storage tank operated by LBT	Some flooding (pumps survived, flooding came to within 1" of motor); Water main breaks due to wash over and erosion.

- **Information Source:** Water and Sewer System Manager, LBT DPW
  www.longbeachtownship.com/departments/water-sewer

Key Findings

What sped up the critical path to recovery?

- Trucks were evacuated to the mainland prior to landfall and, as a result, were undamaged and available for recovery work.
- LBT water and sewer staff worked 12 hours/day x 7 days per week during the response phase.
- Support contracts were in place ahead of the event with engineering firm (Owen, Little & Associates) and a contractor (P & A).
- Damage was concentrated in the two southernmost sections (Brant Beach and Holgate). Northern four sections were largely undamaged.
- LBT commandeered a supermarket parking lot as a place to stage debris as roads were being cleared.
- A diesel generator was brought in to keep the Peahala Park tank filled so that there would be (non-potable) water at the LBT municipal building.

What slowed down the critical path to recovery?

- Loss of electric power (first few days).

- Natural gas used to power back-up generators at pump stations shut off. Time line from https://www.njng.com/safety/hurricane-sandy-updates/archived-updates.aspx
  - Gas service shut off on November 1
  - Restoration on LBI began on November 11
  - 43% of LBI service restored as of November 18
  - 88% of LBI service restored as of November 24
  - 98% of LBI service restored as of November 26

- Tanks were full pre-event, but broken water mains in Holgate caused the Holgate tank to be emptied. Back-up generator powered by natural gas was running and tank was half-full again when gas supply was shut off due to widespread gas leaks. This depressurized the system, resulting in a boil water advisory which continued into December.

What is being done to speed up the recovery process for potential future events?

- The township now has a hazard mitigation plan in place that would facilitate the recovery process.
- Pumps and water treatment equipment have been elevated to the 500-year flood level (Elevation 16 ft.) at Holgate and Beach Haven Terrace. Brant Beach will be next.

Recommendations for what else could be done to help with potential future events?

- Complete elevation of pumps and water treatment equipment to 500-year flood level.
- Consider diesel back-up power as an alternative to natural gas?

Critical Path to Recovery Details

Hurricane Sandy made landfall on October 29, 2012. Initial damage to water system is summarized above. The first key recovery milestone occurred when non-potable water service was restored to the LBT municipal building, which was the command center for the township's recovery effort. The second key recovery milestone was the restoration of non-potable water throughout LBT, except Holgate. This milestone was reached before the island was reopened to homeowners and business owners on 10 November. The third key milestone was the repair and re-pressurization of the Holgate section. This milestone was reached in phases over a period of about one month. The fourth key milestone was the removal of boil water advisories. This milestone was reached in December. The critical paths to recovery for each of these milestones are detailed below.

Critical Path to Restoration of Non-Potable Water Service at LBT Municipal Building

Table 4 and Figure 1 present the critical path for restoration of non-potable water service at the LBT municipal building.

Table 4. Critical path for restoration of non-potable water service at LBT Municipal Building

#	Activity	Duration	Notes
1	Sandy Hits	Day 0 to Day 1 (1 day)	
2	Natural gas shut-off	Day 2 (1 day)	Natural gas service shut off due to numerous leaks throughout the service area.
3	Bring in tanker truck with non-potable water	Day 2 to Day 4?	Trucked-in non-potable water used to refill toilets at municipal building. Plenty of bottled water was available for drinking.
4	Acquire portable diesel generator for Peahala Park	Day 2 to Day 4?	Pump at Peahala Park was not inundated, but back-up power was no longer available after natural gas was shut-off.
5	Refill Peahala Park storage tank	Day 3-4?	Refill storage tank and restore pressure to LBT municipal building

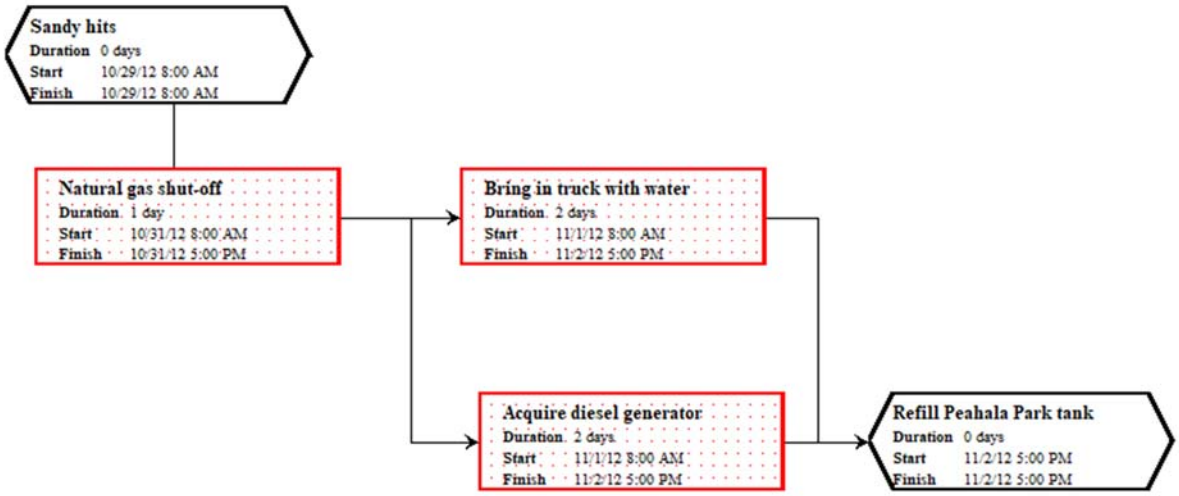


Figure 1. Critical path network diagram for restoration of non-potable water service at LBT Municipal Building.

No near critical path activities were identified for this milestone. There was some loss of communication until cell towers were repaired/replaced. This was resolved early on and was not a critical or near-critical path issue for the water system restoration. There were no significant issues with accessing areas were repairs were needed.

Critical Path to Restoration of Non-Potable Water Service to all of Brant Beach

Table 5 presents the critical path for restoration of non-potable water to the entire Brant Beach section of the LBT water system. By November 10, all customers had service with boil water advisory, except for the Holgate section at the southernmost end of the island.

Table 5. Critical path for restoration of non-potable water service to all of Brant Beach

#	Activity	Duration	Notes
1	Sandy Hits	Day 0 to Day 1 (1 day)	
6	Electric power restored	Unknown	
7	Temporary electric motors installed	Unknown	Pump motors damaged by salt water flood inundation at two of three locations in Brant Beach. Temporary motors used while permanent motors were rewired and coils were rewound, which took about 1 month.
8	Refill Brant Beach storage tanks	Unknown	
9	Flush out Brant Beach fire hydrants	Day 12	Flush out hydrant-by-hydrant, working away from each water storage tank

In addition to the above critical path activities, one near-critical path activity was identified:

1) **Flush out well #3 in Brant Beach**: One of two wells at Brant Beach was contaminated by flood water and had to be flushed out twice. However, there is another well at the same site which did not become contaminated. Therefore, this did not become a critical path activity.

Critical Path to Restoration of Non-Potable Water Service to Holgate

Table 6 presents the critical path for restoration of non-potable water throughout LBT. Holgate was last section to re-open. The first portions of Holgate re-opened by Thanksgiving.

Table 6. Critical path for restoration of non-potable water service to Holgate

#	Activity	Duration	Notes
1	Sandy Hits	Day 0 to Day 1 (1 day)	
10	Repair broken water mains in Holgate	Unknown	Water mains damaged by over wash and erosion in the area between Webster and Rosemma Avenues.
11	Flush out Holgate fire hydrants	Day 24 to ~Day 30	Flush out hydrant-by-hydrant, working away from the water storage tank

In addition to the above critical path activities, three near critical path activities were identified:

1) Electric power restored
2) Temporary electric motor installed
3) Refill storage tank

These three activities correspond to activities 2-4 in Table 5, but they were not on the critical path for the Holgate sector because the water main repairs took longer.

Critical Path to Restoration of Potable Water Service

Table 7 presents the critical path for restoration of potable water. This milestone was reached in December. Table 7 is a continuation of Table 4 through Table 6.

Table 7. Critical path for restoration of potable water service

#	Activity	Duration	Notes
12	Resumption of normal water treatment processes	Varied by location	Filters and tanks were undamaged. No issues with chemical supplies. There was some loss of lime due to inundation, but this was neither critical nor near-critical. Other chemicals were moved to higher ground before the event. Chlorine rooms were not flooded.
13	Water quality testing	Varied by location	Long Beach Island Health Department
14	End boil water advisory	~Day 40	Long Beach Island Health Department

Additional notes:

1) No delays in recovery due to long lead times for delivery of replacement parts. All fairly standard items.
2) No issues with unusual delays for inspections, permitting, or engineering. Team was able to get to work quickly and work unimpeded.
3) Water quality was impaired into December. Approval by LBI (not LBT) Health Department and NJ Department of Environmental Protection (DEP). LBI Health Department serves the entire island and is located in Ship Bottom, NJ.
4) No temporary water lines were installed.
5) Freezing weather came in December which resulted in some burst pipes at vacant vacation houses where water had not been shut off by owner. This happens every winter.

Steps taken since Sandy:

1) Elevating pumps and water treatment equipment above the 500-year flood plain (Elev. 16 ft.)
2) Beach Haven Terrace is done (NJ Environmental Trust funding)
3) Brant Beach is done
4) Holgate is next

LBT adopted Ocean County 2014 Hazard Mitigation Plan (after Sandy).

LBT consulting engineer is Owen, Little and Associates (POC: Frank Little). Contracts were in place ahead of time.

A-2: Water Supply Recovery in Monroe County, Florida (Hurricane Irma)

Water System Information

- **Provider:** Florida Keys Aqueduct Authority (FKAA)
- **Monroe County 2010 Population**: 73,090
- **Customer(s):** Serve 49,123 customers with 1,086 miles of pipeline.
- **Critical customer(s):** US Navy base.
- **Sections and Damage**:
  - 130 miles of main (36" to 12" ductile iron pipe?) from Florida City water treatment plant in Miami-Dade County to Key West along US Highway 1.
  - 690 miles of (12" to 2") distribution lines off the main trunk
  - Damage: "Death by a thousand cuts" – water treatment plant and main trunk line were undamaged; plant and pumps operated continuously on backup diesel. All leaks were on distribution lines off the main trunk, at customer meters, and on the customer side of the meters. Full service with boil water advisory restored by Day 13. Full service without boil water advisory restored by Day 15 (September 25, 2017).

Section	Description	Damage
Upper Keys	North of Long Key Bridge	Continuous service with reduced pressures and boil water advisories
Middle Keys	Long Key Bridge to 7-mile Bridge	Some damage. Includes Marathon.
Lower Keys	South of 7-mile Bridge to Key West	Heaviest damage. Restoration started at both ends (Big Pine Key in the North and Key West in the South) and worked toward Summerland Key in the middle, which was the last are restored.

- **Information Source:** Manager of Operations

Key Findings

What sped up the critical path to recovery?

- Most of their vehicles were evacuated to the mainland prior to landfall and, as a result, only 17 were lost.
- Storage tanks were all topped off and valves closed before landfall. This made them less vulnerable to wind damage. Closing valves prevented loss of water when leaks started.
- Lack of damage to bridges on U.S. 1 meant no damage to water main. This is FKAA's biggest vulnerability.
- Fairly rapid safety assessment of bridges on U.S. 1 by DOT also meant that FKAA crews could assess the system and determine how much restoration assistance to request.

- Some assistance came via WARN (in-state network) and more from EMACS (out-of-state network). A total of 10 crews (4-6 workers per crew) were added to FKAA's in-house crews and local contractor crews.
- FKAA estimates 24 to 30 crews were operating at the peak of restoration activities.
- Crews from other utilities were initially provided for two weeks, but they all agreed to extend for two additional weeks at FKAA's request. Extending existing crews was preferable to bringing in new in-state crews because the existing crews had already become familiar with the system.
- Loss of electric power was not a significant issue. Diesel fuel supply (about 7 days) was sufficient.

What slowed down the critical path to recovery?

- Security checkpoints on roads denied access. This was a sporadic problem. Even uniformed employees were denied access in some cases.
- Communications were difficult, particularly for the first 6-7 days until cell phone service and fiber were restored and fairly reliable. Radio communications worked, but only for a 10-mile range from Key West initially (not far enough to reach areas of heaviest damage).
- Re-entry by residents created more traffic on U.S. 1, increasing travel times for restoration crews.
- Damage to FKAA equipment during debris removal operations. Debris was piled up along right of way – around and on top of FKAA meters and valve vaults. Average of 36 new leaks per day during major debris removal operations in October and November.

What is being done to speed up the recovery process for potential future events?

- Bring extra fuel for vehicles. 5-gallon cans are cheap.

Recommendations for what else could be done to help with potential future events?

- Protect SCADA antennas
- Put contracts in place for emergency lodging and meals for work crews
- Get internet service from multiple providers

Critical Path to Recovery Details

Hurricane Irma made landfall on September 10, 2017. This was the first hurricane to produce a water outage in the Florida Keys since Hurricane Donna in 1960. Initial damage to water system is summarized above. The first key phase was the restoration of potable water service throughout all water mains and most distribution lines by day 15 (September 25, 2017). The critical paths to recovery for each of these phases/milestones are detailed below.

Critical Path to Restoration of Pressure in Main Trunk Line from Florida City Treatment Plant to Key West

Table 8 presents the critical path for restoration of pressure along the full length of U.S. 1 to Key West. This was accomplished by verifying the main trunk was undamaged and shutting off all of the master meter taps off the main trunk.

Table 8. Critical path to restoration of pressure in main trunk line from Florida City Treatment Plant to Key West

#	Activity	Duration	Notes
0	Pre-storm preparation	Days -4 to -1	Top off storage tanks and shut off valves. Evacuate personnel, vehicles, and servers
1	Irma makes landfall in the Lower Keys	Day 0	September 10, 2017
2	DOT Inspection of U.S. 1 Bridges	Day 1	Confirmed no significant damage to bridges or water main sections supported by bridges; allowed access to areas requiring repairs
3	Re-entry of FKAA crews	Day 1	
4	Damage assessment	Days 1-2	By FKAA personnel
5	Restoration of pressure along the full length of U.S. 1 water main	Days 3-4	Shutting off all ~150 master meter taps to prevent loss of water and pressure

No near critical path activities were identified for this milestone. There was significant loss of communication during the first week until temporary cell towers were in place. Loss of communications did not delay restoration process, but recovery of cell service made things easier.

There were no significant issues with accessing areas were repairs were needed.

Another activity that occurred on Day 2 was the re-opening of the FKAA offices in Key West. This provided an opportunity for customers who did not have phone, internet, TV, or radio service to make direct inquiries.

Critical Path to Widespread Restoration of Non-Potable Water Service

Table 9 presents the critical path for restoration of non-potable water. This was accomplished by opening up master meter taps one-by-one, finding and repairing leaks on distribution lines one-by-one, and shutting off valves at meters that had leaks on the customer side of the meter. After this milestone, there were only isolated leakages on small distribution lines and/or individual customer service lines.

Table 9. Critical path to widespread restoration of non-potable water service

#	Activity	Duration	Notes
4	Damage assessment	Days 1-2	By FKAA personnel
6	FL WARN and EMAC requests	Day 2	Detailed requests for outside help. Initially within Florida via WARN and then to utilities in other states via EMAC
7	Outside crews arrive	Days 3-5	10 crews (4-6 workers per crew)
8	Repairs and ongoing assessments	Varies by Key	Worked from each end of Lower Keys
9	Restore water service with boil water advisory	Varies by Key Completed Day 13	Day 13 (Sept. 23) was last (Summerland Key).

Clearing of roads was fairly rapid and did not significantly impede system repair work.

Power outages, up through Days 12-15 in parts of the middle Lower Keys, did not significantly impede system repair work. Work crews had the resources they needed to perform their work.

Re-entry by residents during this period created more traffic on U.S. 1, increasing travel times for restoration crews.

Critical Path to Restoration of Potable Water Service

Table 10 presents the critical path for restoration of non-potable water. FKAA avoided contamination of water by continuously producing potable water at their Florida City plant and isolating leaking areas of the system. All but a handful of water quality tests passed on the first attempt. The few that failed were not serious issues and passed when re-tested the next day.

System Issues beyond Restoration of Potable Water Service (Day 15)

The second major phase was the completion of major debris removal operations in early December. During debris removal, an average of 36 new leaks per day were discovered or occurred when debris removal equipment damaged meters and vaults.

Administrative Issues

The second major phase was/is an administrative phase, including billing adjustments (“abatements”) and preparation of documentation for FEMA disaster assistance (ongoing).

Table 10. Critical path to widespread restoration of potable water service

#	Activity	Duration	Notes
9	Restore water service with boil water advisory	Varies by Key	Day 13 (Sept. 23) was last (Summerland Key).
10	Test water	Varies by Key	680 samples taken. Up to two tests per location. 24 hours to get results.
11	Lift boil water advisory	Varies by Key Completed Day 15	Day 15 (Sept. 25) was last (Summerland Key).

Additional notes:

1) No delays in recovery due to delays in the availability of materials or equipment.
2) Main limiting factor was the number of crews that FKAA could productively use, which determined the size of their requests for assistance via WARN and EMACS. FKAA received all of the assistance that could effectively deploy and manage.
3) No issues with unusual delays for inspections, permitting, or engineering. Team was able to get to work quickly and work unimpeded.

A-3: Water Supply System Recovery in Houston, Texas (Hurricane Harvey)

Water System Information

- **Employees:** 4,000
- **Demand:** 500 million gallons per day
- **Capacity**: 644 million gallons per day across three plants (all 3 plants are needed to meet demand with enough pressure)
- **Damage:** Water service was never lost. Out of 159 storage tanks, only 2 were damaged. The two damaged tanks were at Meyerland and Belleau Woods – HPW is seeking FEMA reimbursement for the damage of these two sites. There was some damage at the customer demand end where hoses to washers and refrigerators were broken causing leaking. This led to some high bills for some customers, which were forgiven by just charging those customers at their 12-month average. FEMA did not compensate Houston for the cost of supplying this water to the public.
- **Information Sources:** Houston Public Works

Key Findings

What helped to prevent service disruption?

- Ensure there are enough supplies and food for staff left in place in case it is challenging to rotate in replacement staff.
- Following Hurricane Ike in 2008, a full-time emergency coordinator position was created and the department's emergency response plan was updated. All staff were designated as Tier I, Tier II, and Tier III to make it clear who is required to be on duty during a storm and shortly after.
- Every plant has a backup generator. This was required as a legislative response to issues with Hurricane Ike.

What were obstacles to normal operations?

- Biggest challenge was access to treatment plants until flooding receded.
- There was concern of limited chemical availability for a specific polymer that is used for charge neutralization in the treatment process at one of the three water treatment plants. Because of the higher dosages, the chemical was used quicker; and fortunately, the department was able to re-supply the product once the flood waters receded.
- It became necessary to procure tiger dams to keep flood waters out of the backwash pond at the Northeast treatment plant.
- Debris removal operations around the service area resulted in some smaller leaks (a few dozen).
- There was a public perception that the water was not safe to drink. People posted on social media that the water was not safe.

Recommendations for what else could be done to help with potential future events?

- Build an "N+1" water treatment system so any one plant could go down without interruption to service. The City of Denver has this capability.
- Forms for contractors should be made FEMA-compliant, and this should be done before the event. Non-compliant forms led to some contractors getting paid 8 to 9 months later.

A-4: Water Supply Recovery in Port Aransas, Texas (Hurricane Harvey)

Water System Information

- **Sections and Damage**: Port Aransas purchases treated water from Corpus Christi (76%) and Aransas Pass (24%). There was no major damage to water infrastructure (pumps and water mains) in Port Aransas. The line from Corpus Christi to Port Aransas was damaged, which led to a loss of ¾ of the water supply capacity. Additionally, water was lost at the customer sites, which took away pressure from the overall system.
- **Information Source:** District Manager

Key Findings

What sped up the critical path to recovery or prevented disruption?

- Support from San Antonio: Through the Texas WARN system, Port Aransas received support from a crew from San Antonio who brought 26 people, 2 generators, backhoes, skid steers, and other equipment.
- Finding places for the crews to sleep and eat: There were some new constructions with beds and bedrooms that the crews were able to use. This meant shorter commutes, more work time, and better morale.
- Ability to operate manually with SCADA system. The SCADA system is still not back up 17 months following Harvey.
- Dedicated staff: All the staff returned and postponed dealing with their own property problems to put the water supply first. Many came as early as Day 2.
- Quick access to the island. Mark was local and able to quickly assess the situation.

What slowed down the critical path to recovery or were obstacles to normal operations?

- Loss of all equipment as facility with all equipment (six trucks and one water truck totaled) was flooded several feet. Port Aransas needed to wait three days until San Antonio in order to begin accessing and shutting down meters
- GIS of meter valves would have helped. The water district employees knew where they were relative to other landmarks, but many of those landmarks were gone or buried from Harvey.
- Debris: Power poles, wires down, boats, RVs, dead vehicles, made getting around the island slow.

Recommendations for what else could be done to help with potential future events?

- Build a command center above flood levels. This would allow for personnel brought in to eat, sleep, and meet. As it turned out, there was a 10-bedroom undamaged new construction they were able to use as a command center. This helps with communication and reduces time commuting to and from where workers are staying.

- Help understanding the FEMA process. This did not impact the path to providing water; however, Port Aransas is still waiting to replace their SCADA system 17 months later and is operating manually. This is partly because of the confusion about what to provide FEMA to make sure they get reimbursed for related purchases.
- Securing food and resources ahead of time. As it turned out, a restaurant owner provided food and supplies and the water district was able to use this to cook for 60 people for some time.

Critical Path to Recovery Details

Table 11 and Figure 2 present the critical path to recovery to regain full water pressure with a boil advisory (after five days) and Table 12 presents the critical path to restoration of water with the boil advisory removed (after 14 days). Even with 76% of water volume not available because Harvey washed out the line from Corpus Christi, Port Aransas provided water within five days

Table 11. Critical path for restoration of non-potable water service

#	Activity	Duration	Notes
1	Hurricane Harvey Hits	Day 0 (8/25/17)	August 25, 2017
2	Support from San Antonio and other from Nueces county arrive	Day 1 to Day 3 (3 days) (8/28/17)	San Antonio brought equipment, 2 generators, and 26 people. Nueces County #3 also brought 8 men.
3	Shut off all meters to prevent bleeds at customer sites	Day 4-5 (2 days) (8/30/17)	This was somewhat of a challenge without a GIS-based system for valves as the normal "landmarks" near the valves were washed away in many instances. This was also slowed down by debris all over the island.
4	Re-charge (pressure) the water system	Day 5 (< 1 day)	Once the meters were shut off, they were able to pressurize the water system slowly.
5	Water restored with boil advisory	Day 5 (8/30/17)	Water was running on 24% capacity (from Aransas pass). This was enough because demand was low. The 76% from Corpus Christi was not available because of a broken line.

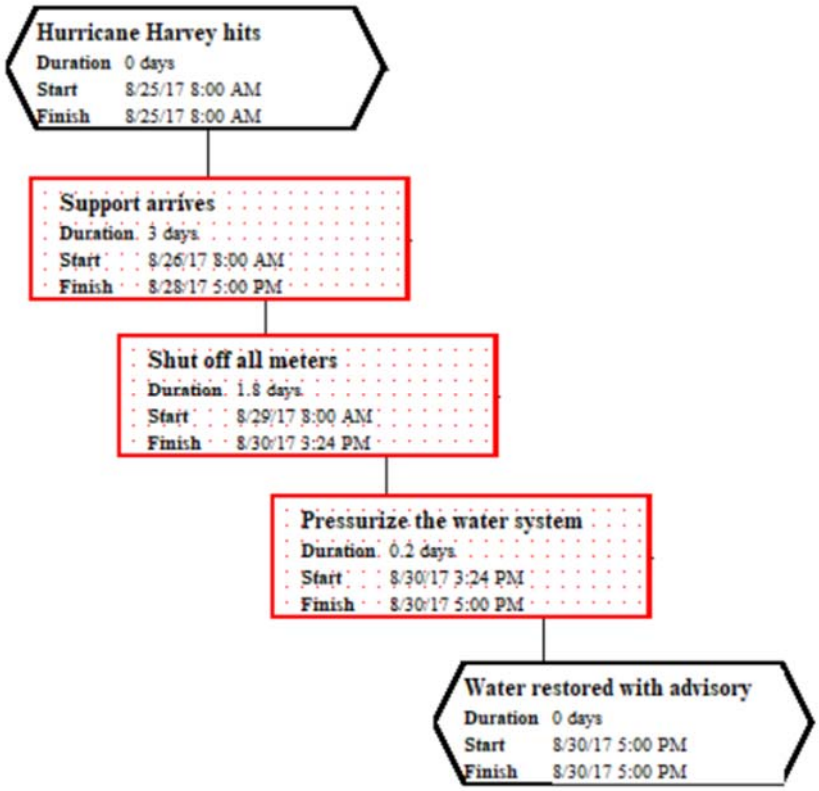


Figure 2. Critical path network diagram for restoration of non-potable water service

Near-critical path items:

- **Bringing in generators to run pump stations**: These were up and running by day 4 or day 5 (slightly before all the meters were shut off). Finding and fueling generators nearly drove the critical path to providing water.

A 20'' line from Corpus Christi that fed Port Aransas' pump station had been washed out. This line provided about 76% of water volume wash washed out completely at Packery channel. The critical path for full water pressure with boil advisory removed was dependent on fixing this line, flushing, and testing water. Details are provided in Table 12 and Figure 3.

Table 12. Critical path for restoration of potable water service

#	Activity	Duration	Notes
1	Hurricane Harvey Hits	Day 0	August 25, 2017
2	Corpus Christi fixes water line into Port Aransas.	Days 1-10 (10 days)	This line brings 76% of water volume to Port Aransas.
3	Flush water systems and test water.	Days 11-13 (3 days)	After Corpus Christi line was restored, flushing and testing was needed before removing boil advisory.
4	Get lab test back to pass water quality standards	Day 14 (1 day)	Water quality passed.
5	Water restored with no boil advisory.	Day 14 September 8, 2017	

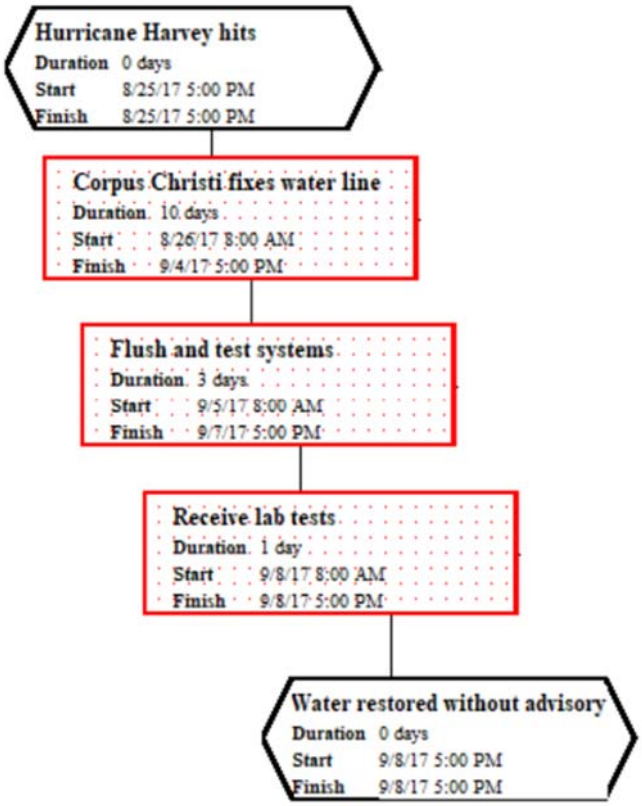


Figure 3. Critical path network diagram for restoration of potable water service

Near-critical path activities included:

- **Electricity:** This came on day 11, and even without electricity, the generators would have been able to run the system.

A-5: Water Supply System Recovery in the US Virgin Islands (Hurricanes Irma and Maria)

Water System Information

- **Sections and Damage:** The USVI Water and Power Authority (WAPA) has two districts – one serving St. Thomas and the neighboring island of St. John and a second serving St. Croix. At the time of the two hurricanes, the total population of the USVI was about 106,000. However, a significant percentage of homes in the USVI have rainwater collection systems and cisterns to store and treat their own water. As a result, the approximately 13,000 accounts served by WAPA are primarily public facilities, businesses, resorts, and city residents. Following Hurricane Irma, which struck on September 6, 2017 and mainly damaged the St. Thomas district, the St. Thomas district received considerable recovery support from the St. Croix district and Puerto Rico. However, when Hurricane Maria struck St. Croix and Puerto Rico two weeks later, on September 19 and 20, much of the initial outside assistance was diverted back to their home bases. In the St. Thomas district, the heaviest damage from Hurricane Irma was on St. John and the northeastern side of St. Thomas. The desalination plant at Krum Bay on the southern coast of St. Thomas was mostly undamaged, except for a few lost panels on the dome of one production tank.
- **Information Sources:** St. Thomas and St. Croix District Managers

Key Findings

What sped up the critical path to recovery or prevented disruption?

- VITEMA (Virgin Islands Territory Emergency Management Agency) located close by. Daily meetings kept everyone informed and coordinated.
- Outside support, initially from St. Croix and Puerto Rico and later from the U.S. Department of Energy and the Corps of Engineers.
- Absence of storm surge damage. Water treatment and storage facilities located above the areas inundated by storm surge
- Ability to operate the system manually. No SCADA yet.
- Dedicated staff: All the staff returned and postponed dealing with their own property problems to put the water supply first. Many came as early as Day 2.

What slowed down the critical path to recovery or were obstacles to normal operations?

- Loss of power: Neither district had sufficient backup generation capacity in place prior to the storms to serve all of their customers, particularly those located at higher elevations. Procurement and installation of generators was the primary critical path activity.
- Severely disrupted transportation: Downed trees, fallen power lines, boats washed ashore, non-functioning vehicles, lack of traffic signals, narrow roads, airport restrictions, and loss of ferry service made getting around the islands difficult and very slow. Some improvement around Day 3 or 4 after effective curfew

enforcement was put into place. Of the two barges used to ferry cars between St. Thomas and St. John, one sank and the other was heavily damaged. It took about 1 month before local residents could use the barges, and then only at set times.

- Loss of communications: No cell phone service for first 3-4 days, very limited service directly under towers through Day 7, and slow improvement thereafter. It took about 1 month to return to close to normal service. WAPA did not have radio communications.
- Some staffing issues for the first 5 days to two weeks due to difficulties in moving about the islands, staff needing to find a place to live, and staff being stuck off the islands and unable to return.

Recommendations for what else could be done to help with potential future events?

- Reliable backup generation capacity in place prior to the storms.

Critical Path to Recovery Details

Table 13 and Table 14 presents the critical path to restoration of service throughout the St. Thomas and St. Croix Districts, respectively. In both districts, procurement and installation of generators was required to restore service. That activity was completed in both districts by mid-October. In the west end of St. Croix, and additional month of repairs were needed to restore reliable water service to customers.

Table 13. Critical path for restoration of service throughout the St. Thomas District

#	Activity	Duration	Notes
1	Hurricane Irma hits September 6, 2017	Day 0	Hurricane Irma was a category 5 storm that passed over the northern parts of St. John and St. Thomas.
2	Repair storm surge damage to power plant controls at Krum Bay on St. Thomas	Day 7	5.5 million gallon tank at St. Thomas desalination plant almost ran out completely during this time. Rationing had started. After power plant was back on line, the desalination plant was able to operate as needed. Primary issue then became providing power for the pump stations since none were receiving power from the grid and many did not have backup generators. There was enough generator capacity to pump water to the lower elevations.
3	Generators in place at all pump stations	~Day 40	Generators procured and installed by US Army Corps of Engineers at all pump stations

Table 14. Critical path for restoration of service throughout the St. Croix District

#	Activity	Duration	Notes
1	Hurricane Maria hits September 20, 2017	Day 0	Outer eyewall passed near the west end of St. Croix while Hurricane Maria was a category 5 storm. Maintenance work ongoing beforehand had one 5 million gallon tank offline, but another 10 million gallon tank was full. Another 5 million gallon tank serving the west end emptied within hours post-storm.
2	Generators in place at all pump stations	~Day 26	Generators procured and installed by US Army Corps of Engineers at all pump stations
3	St. Croix west end repairs and restoration	~Day 56	Service to the west end of St. Croix was still a struggle after generators were brought in, and it took about 1 more month to restore reliable service.

A-6: Water System Recovery in Waterbury, Vermont (Hurricane Irene)

Water System Information

- **System Information:** Continuity of service was maintained due to the availability of two sources of raw water about eight miles from the center of town: surface water from mountain runoff and deep rock wells. The system is gravity fed. The community also benefited from the absence of any damage to water mains and the presence of gravity flow throughout the system. Following Hurricane Irene, the town shut off its mountain stream intakes and switched to the wells. The alternative source gave the town time to clear debris from the surface water intakes and to let the turbidity of the surface water settle down.
- **Customers:** About 1,000 customers.
- **Damage:** Customers never lost potable water, but there was damage to the system. In advance of the storm, the town switched from using surface water to well water because of expected turbidity issues. At the residential level, many hot water heaters floated away when basements flooded, causing bursts in the pipe connecting to the hot water heater and leaks in basements. The water lines to these homes could only be easily shut off using the curb stop valve. About 200 homes were flooded and many of these had damaged lines and leaks that needed to be shut off using the curb stop valve.
- **Sources of Information:** Municipal Manager and Public Works Director.

Key Findings

What sped up the critical path to recovery?

- Waterbury has redundant water sources and matching reserve capacity. This was important as they were able to switch to well water before the storm in anticipation that the surface water system would go down (which it did for about 7-10 days).

What slowed down the critical path to repairing the water system?

- Because everyone still had drinking water, the public works staff prioritized non-water related work such as fixing sinkholes and removing debris. This caused the removal of rocks from the surface water impoundment dam to occur about a week after the storm instead of in one to two days.
- It took a few weeks to shut off all the curb stop valves because many were buried by debris and some valves were damaged during the storm and had to be repaired prior to being shut off.

What is being done to speed up the recovery process for potential future events?

- Waterbury purchased a generator for the water treatment center. This could have potentially been an issue if the power was out for longer, but it did impact this event.

Critical Path to Recovery Details

Hurricane Irene was primarily a rain event by the time it made it to Northern Vermont on Sunday, August 28, 2011. Saturated grounds from a wet summer caused more water to run into the river. Below, we present two critical paths to repairing the surface water system and returning to normal delivery to residential customers.

Critical Path to Restoring Surface Water System

Table 15 and Figure 4 show the critical path to restoring the surface water system. This is one of two systems that provides water. Customers had water provided through well water during this time.

Table 15. Critical path to repairing the surface water system

#	Activity	Duration	Notes
1	Irene hits on Sunday, August 28, 2011	Day 0	Heavy rain caused the river to rise several feet above the 100-year flood plain.
2	Clear rocks out of the surface water impoundment dam	Days 1-10 (10 days)	This would normally take about two days to clear rocks out of the impoundment area with a backhoe but took about ten days because public works staff prioritized other non-water related work. This would have been more of a priority if customers did not have uninterrupted water supply through the well water.
3	Public works fills impoundment back up with water.	Day 10 (hours)	After the rocks were cleared, they closed the drain and filled back up with water for the town.
4	Town switches back to surface water from well water.	Day 10	At this point, there were still many curb stop valves not yet shut off, causing severe leaking in the basements of about 200 homes. It took about 3 weeks to identify all of the leaks and turn off all curb stop valves.

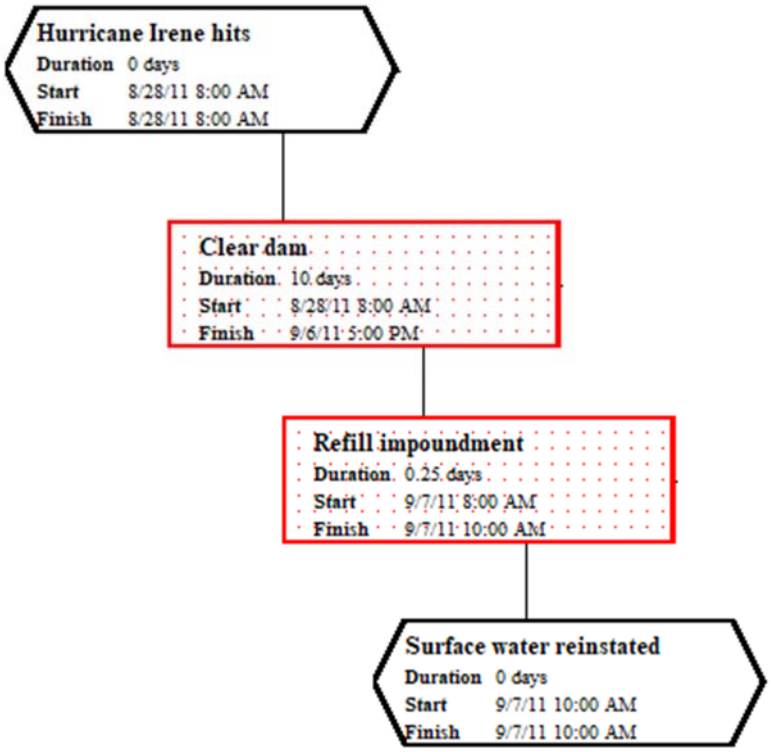


Figure 4. Critical path network diagram for repairing the surface water system

Critical Path to Return to Normal Delivery

Table 16 and Figure 5 show the critical path to more normal delivery to customers. The flood impacted about 200 of the 1,000 customers, and many of those needed the curb stop valves shut off by public works because hot water heaters floated and disconnected from pipes causing flooding in basements.

Table 16. Critical path to more normal delivery to residential customers

#	Activity	Duration	Notes
1	Irene hits on Sunday, August 28, 2011	Day 0	Heavy rain caused the river to rise several feet above the 100-year flood plain.
2	Public works shuts off curb stop valves where needed	About 3 weeks	This was slowed down by debris on curb stop valves and about 1/3 of the valves being damaged or older and harder to turn off. Additionally, with public works dealing with other issues (sinkholes and debris removal), there was less availability early on to deal with these issues.
3	Public works turns back on curb stop valves as houses complete plumbing fixes	Many weeks	This varied dramatically by house, but plumbers fixed the majority of leaks in residences over several weeks and public works turned back on the curb stop valves on a rolling basis as repairs were completed.
4	More normal delivery to customers	About 1-2 months later	At this point, the delivery of water to residences was about the same as pre-Irene levels; however, delivery volume/ revenue was still less than pre-Irene levels as 1,500 state workers moved to a new location for 51 months (until November 2015).

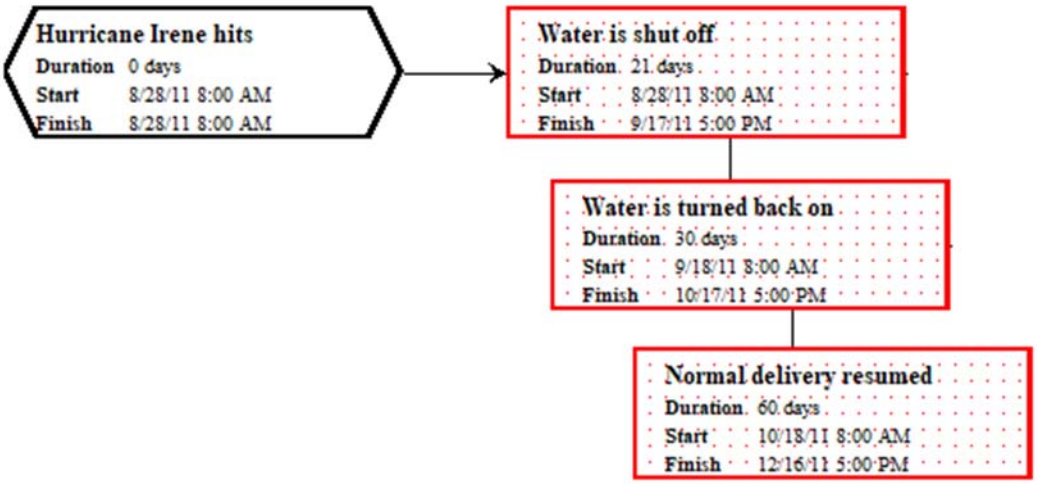


Figure 5. Critical path network diagram for more normal delivery to customers

Critical Path to Pre-Event Revenue for the Water

As noted in Table 16, the 1,500 state workers moved buildings after Hurricane Irene and did not return to the area for 51 months (until November 2015). At this point, water revenue was close to pre-Irene levels (slightly lower because of new water-efficient fixtures in the new State buildings).

Appendix B: School Critical Path Case Studies

- B-1: Long Beach Township, NJ (Hurricane Sandy, 2012): Long Beach Island Consolidated School District
- B-2: Monroe County, FL (Hurricane Irma, 2017): Monroe County School District
- B-3: Houston, TX (Hurricane Harvey, 2017): Houston Independent School District
- B-4: Port Aransas, TX (Hurricane Harvey, 2017): Port Aransas Independent School District
- B-5: Tuscaloosa, AL (2011 Tornado Outbreak): Tuscaloosa City School District
- B-6: Waterbury, VT (Hurricane Irene, 2011): Harwood Unified Union School District
- B-7: St. Thomas, USVI (Hurricanes Irma and Maria, 2017): STTJ School District

B-1: Long Beach Island Consolidated School District (Hurricane Sandy)

School Information

- **School 1:** Ethel Jacobsen Grade School (EJ), Surf City, NJ (pre-K to 2nd grade)
- **School 2:** Long Beach Island Grade School (LBI), Ship Bottom, NJ (grades 3-6)
- **Combined Enrollment:** About 240 (about an equal split at both schools)
- **Employees:** 28
- **Damage:**
  - No damage inside EJ School; clean-up of exterior debris required. Purchased and installed 500 gallon electric water heater to use temporarily until natural gas service was restored on the island.
  - Boiler room below first floor at LBI School was inundated by storm surge, but the flooding did not reach the first floor. Some roof cover damage, but no leakage into building. Classrooms, offices, etc. on first floor were undamaged.
- **Information Source:** District Facilities Manager

Key Findings

What sped up the critical path to recovery?

- To get the EJ School back up and running in about two weeks, it was important to get an initial assessment of both schools done quickly. The school's facility lead was also a former firefighter—this connection to emergency personnel helped provide access to the schools as soon as the storm ended for an initial assessment.
- The Connect Ed emergency contact system was already in place which made it easy to communicate to parents and students about the plans to reopen the EJ School.
- Generally, all communications and decisions went through a central point. There were limited times where uncoordinated decisions were being made by multiple entities at once.

What slowed down the critical path to recovery?

- Concerns from parents about putting students in modular units slowed down the process of putting in temporary classrooms.
- Fears about mold slowed down the process of repairing the LBI School as some parents were concerned that the school environment may be unsafe.
- The competition for modular units to use as temporary classrooms also made it more difficult to find and install the classrooms, which provided an overall minor delay in the process of creating additional temporary space.
- The ability to consolidate students in the EJ School lowered the urgency to repair the LBI School—the lack of an immediate need likely allowed more meetings to occur about the future of the district without an immediate need for repairs of the LBI School.

What is being done to speed up the recovery process for potential future events?

- The township now has a hazard mitigation plan in place that would facilitate the recovery process.

Recommendations for what else could be done to help with potential future events?

- The vision for the school district was the primary factor in the delay to get the LBI School open—there were many meetings about whether to consolidate the schools and/or repair the LBI School. Having a plan and a vision for the school district prior to the events may help prioritize and implement recovery activities.

Critical Path to Recovery Details

There are two schools in the Long Beach Township district: EJ and LBI Schools. Hurricane Sandy made landfall on October 29, 2012 and left EJ relatively untouched; however, LBI's boiler room, which was below the first floor, was heavily damaged. The first key milestones occurred when EJ opened just over two weeks later as students from both schools were consolidated in EJ. The second key milestone was the addition of modular units in May of 2013 to serve as temporary classrooms to reduce the crowding. The third key milestone explored below is when LBI opened almost 17 months later on March 18, 2014. The critical paths to recovery for each of these milestones are detailed below.

Critical Path to EJ School Opening

Table 17 presents the critical path to reopening the EJ School on November 13, 2012—approximately 15 days after the disaster. At the point of opening, the school had limitations including all extracurricular/enrichment classes (e.g., art classes) being provided on carts and moved from classroom to classroom (to use those extracurricular rooms as classroom space), and the school had students from both EJ and LBI together in the same building so crowding was an issue. All other operations were deemed normal.

In addition to these above critical path activities, three near-critical path activities were identified:

1) **Electricity came back on**: This was deemed essential to operate, but the electricity came on within six days and did not impact the ultimate timeline of the schools' opening. If electricity had been out for a week or so longer, this would have been part of the critical path.
2) **Acquire and install water heater:** Due to the gas being out for much longer, there was no hot water. This was a relatively quick task that occurred in a day or two and not part of the critical path sequence. This could have been part of the critical path if there were issues finding available hot water heaters.
3) **Move desks and equipment from the LBI to EJ School:** This was done during the daylight as soon as the determination was made to consolidate the schools. This ultimately was not part of the critical path and had several days of slippage that could have occurred before this was a critical path activity.

Table 17. Critical path to EJ School opening

#	Activity	Duration	Notes
1	Sandy Hits	Day 0	
2	Wait for access to island	Day 1 to Day 2 (2 days)	Access was not permitted except for emergency personnel.
3	Initial assessment of EJ and LBI Schools	Day 3 (1 day)	EJ was deemed to have no damage. LBI had substantial was heavily damaged with the boiler. The facilities manager was a former firefighter, which facilitated access to perform the initial assessment of the school prior to access to the island being opened to home and business owners. At this point it was clear EJ would be able to be opened in the short term, but LBI would have a much longer recovery time.
4	Approval from Township Board for students to access EJ School pending the availability of electricity and hot water	Day 4 (1 day)	At this point the decision was made to move all students to the EJ School and the Board approved public access to EJ School—pending the restoration of electricity and hot water. At the time, there was no emergency plan in place for how the Board would convene to make decisions in a situation like this. This was a challenging step, but ultimately it was accomplished over the course of one day.
5	Confirm employee availability	Day 7 (Day 5-6 were weekends) (1 day)	The administration was able to confirm availability of all teachers and school employees to come back to work on Tuesday, November 13 following a Monday holiday for Veteran's Day. The existing emergency contact system in place, "Connect Ed," helped speed up this step with a combination of emails and phone calls to staff. There were no issues connecting with staff.
6	Contact parents to learn about locations and status of students	Days 8-10 (3 days)	Through the Connect Ed contact system parents were contacted by email, text, and phone calls to notify them of the first day of school on November 13 and learn about needed logistics for bussing students, including many who had relocated nearby on the mainland.
7	Renovation	Day 11-14 (4 days)	On Friday and over the long weekend, the school administration planned bussing logistics and provided logistical information about pick-up points for students. This was challenging with the relocation but was relatively seamless. In a couple of cases, there were some misinterpretations of logistical information and pick-up points for a couple of parents who did not speak English as their primary language.

Critical Path to Expanding EJ School with Temporary Trailer Rooms

Several weeks after reopening, it was determined to expand the EJ School with trailers as it was clear the LBI recovery process would be a longer-term project. Table 18 is a continuation of Table 17.

Table 18. Critical path to installation of temporary classroom trailer space at EJ School

#	Activity	Duration	Notes
8	Meetings and decisions about plans for each school	Day 15 to about Month 2 or 2.5 (about 45-60 days)	There was some discussion about consolidating the schools before Sandy. Thus, there were a lot of meetings and discussion about whether to fix LBI and move students there, whether to add some space to EJ, or whether to add trailer space as temporary classroom space at EJ to reduce crowding. Ultimately, it was decided around January 1 to add trailer space at EJ as an interim measure while this decision would be made later. This decision would have been made quicker with a strategic vision prior to Sandy about the future of these schools and potential consolidation. There were also concerns from parents about using trailers as classrooms.
9	Installation of classroom trailers	Month 2.5 to Month 6 (May 2013) (about 4 months)	A few things that slowed this process included the need for footings for the trailers, which added complexities, including the need for digging, electric and utility involvement, and construction office review. The competition for trailers also slowed this process as well as they were in high demand after Sandy. Ultimately, the EJ School settled for some trailers that worked but were not their first choice because of the supply limitations. There were also some challenges in performing this construction with school in session.

Figure 6 is a graphical depiction of the activities described in Table 17 and Table 18.

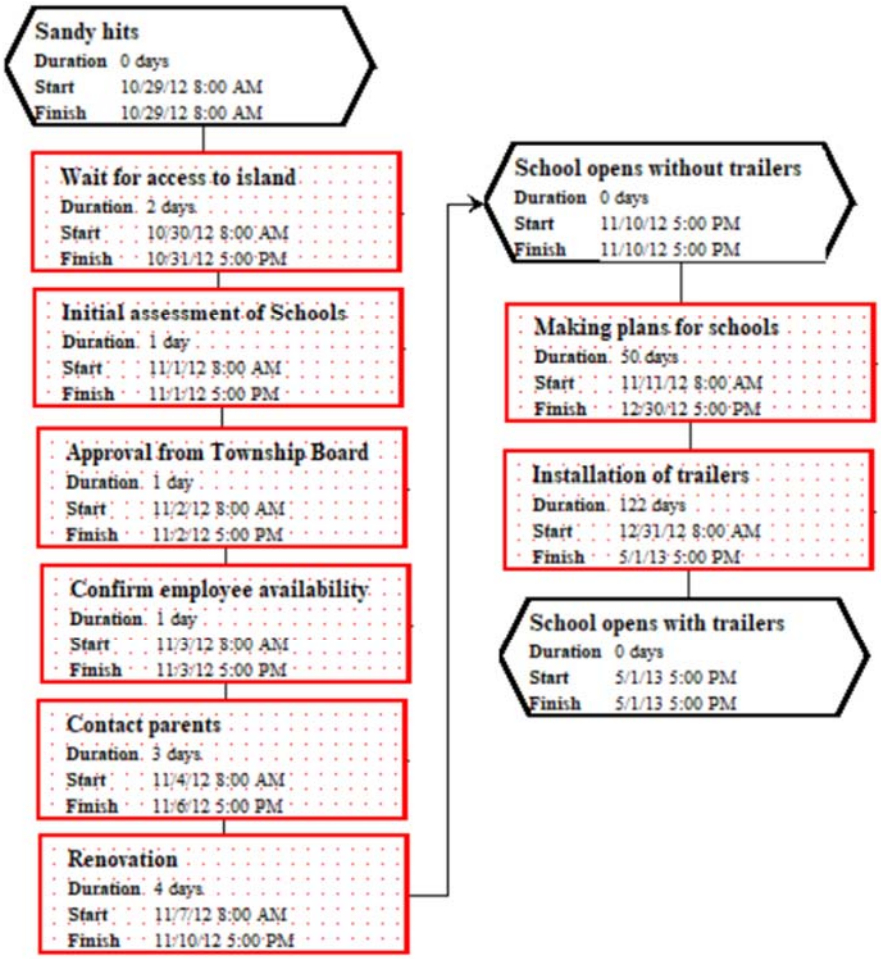


Figure 6. Critical path to opening EJ School without and with temporary trailer space

Critical Path to Opening the LBI School

Table 19 and Figure 7 present the critical path to LBI School reopening. In the absence of the option to consolidate students at the EJ School, it was estimated that it could have been possible to have the LBI School operating in approximately four weeks with temporary equipment supporting operations. This would have involved bringing a generator and other equipment in on a tractor to circumvent the damaged boiler room. However, there were ongoing discussions about consolidating the students into one school prior to Sandy, and this made the decision about whether to repair the LBI School at all.

Table 19. Critical path to LBI School reopening

#	Activity	Duration	Notes
1	Sandy Hits	Day 0	
2	Wait for access to island	Day 1 to Day 2 (2 days)	Access was not permitted except for emergency personnel.
3	Initial assessment of EJ and LBI Schools	Day 3 (1 day)	EJ was deemed to have no damage. LBI had substantial was heavily damaged with the boiler. The facilities manager was a former firefighter, which facilitated access to perform the initial assessment of the school prior to access to the island being opened to home and business owners. At this point it was clear EJ would be able to be opened in the short term, but LBI would have a much longer recovery time.
8a	Meetings and decisions about plans for each school	Day 15 to about Month 4.5 (about 4 months)	There was some discussion about consolidating the schools before Sandy. Thus, there were a lot of meetings and discussion about whether to fix LBI and move students there, whether to add some space to EJ, or whether to add trailer space as temporary classroom space at EJ to reduce crowding. Ultimately, it was decided around January 1 to add trailer space at EJ as an interim measure. Further down the road, around the beginning of March 2013, the school district began moving forward with repairing LBI School.
11	Planning and engineering for relocation of boiler room to higher elevation	About a year	This may have gone slower because there was less urgency with expanded space at the EJ School already being planned and implemented with classroom trailers.
12	Relocation of boiler room to higher elevation and installation of new equipment	6 weeks	Ultimately, this was a fairly short period of time relative to the entire length of recovery.
13	LBI reopens	March 18, 2014 (17 months)	

In addition to these above critical path activities, one near-critical path activity was identified:

1) **Installation of new roof covering**: There was some back-and-forth between FEMA and the school district over whether the roof cover needed to be replaced or just repaired. Eventually, it was agreed that it should be replaced. That said, this activity did not seem to delay the opening of the LBI School in any way.

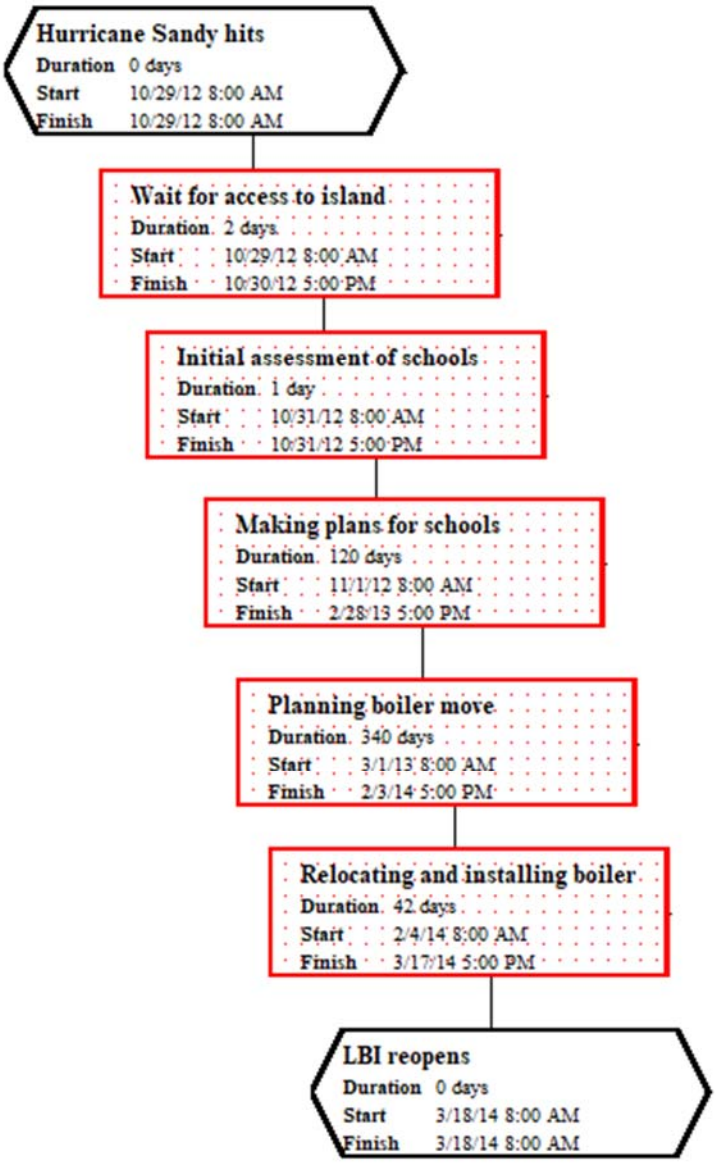


Figure 7. Critical path to opening LBI School

B-2: Monroe County School District (Hurricane Irma)

School Information

- **Schools:** 10 traditional schools and 6 charter schools in the district.
- **Combined Enrollment:** Approximately 8,500 students.
- **Employees:** Approximately 1,000 (teachers, IT, maintenance, transportation, food services)
- **Damage:**
  - Most schools sustained roof damage over some rooms. Sugarloaf Schools sustained the heaviest wind damage.
  - Big Pine Charter School (about 80 K-5 students) sustained the most significant damage as it was the only school to flood (four modular classroom trailers were flooded, and all five of the first floor classrooms of their two-story school were flooded). Their other building (cafeteria) was not flooded.
- **Information Source:** Executive Director of Operations and Planning

Key Findings

What sped up the critical path to recovery?

- Power companies prioritized power restoration to the schools in a few cases, which allowed schools to open at their planned times. Power restoration did not end up being part of the critical path, but it could have been had the power companies not prioritized power restoration.
- 7 of the 10 public schools (and most buildings from one of the other three) have been renovated since 2001 when stricter building codes were put into place. The base of all the schools are one foot above the floodplain and schools are built to withstand winds of 150 miles per hour. Generally, repairs were not on the critical path to recovery, and this is at least partially attributable to the construction of these newer schools.
- The employees had (just) enough time to prepare the schools prior to the storm. This generally involved shuttering and moving potential flying debris to a secure location. These actions likely reduced potential damages, ultimately speeding up recovery.
- Not a recommendation, but approximately 65 percent of maintenance staff stayed through the storm. This allowed for a fast preliminary assessment, which informed decision making and sped up the formal damage assessment once all staff returned.

What slowed down the critical path to recovery?

- This critical path was largely tied to the timeline of the water systems being restored, families returning, and families dealing with their house and other personal needs. See water system case study.
- On the critical path to more normal operations for the Big Pine Charter school, there was a lot of back-and-forth about how to go about implementing repairs (more extensive replacement/renovation or just fix it up for use) and whether they

wanted to restore as was or use the storm damages as an opportunity to make updates. The repairs could have been completed earlier than April, had there been a higher need to reopen those damaged classes or if they had pre-determined what to repair and what to replace in the event of a storm. Having an alternate location for K-1 students lessened the need to immediately repair and reopen the building.

Recommendations for what else could be done to help with potential future events?

- Potentially, having "what if" plans in place for individual schools about when it makes sense to fix versus renovate/replace. This could be based on the age of building, vulnerability to being damaged again, reduced vulnerability with a new building, amount of damage/price of repairs, or how far in the future the school is planning on being replaced.

Critical Path to Recovery Details

Hurricane Irma hit as a Category 4 hurricane on September 9 and 10, 2017 (Day 0 is September 10 in the tables below). In Monroe County, FL there are 16 public schools (10 traditional and 6 charter), and all 16 sustained damaged. For 15 of the 16, the damage was relatively minor and included wind damage but no flood damage. Their critical and near critical paths to opening were all similar and presented in Table 20 and Table 21, respectively. One school, Big Pine Charter, sustained extensive flooding damage and had different critical paths to opening and normal operations, which are presented in **Table 22** and **Table 23**, respectively.

Critical Path to Schools Opening—General Across 15 of 16 Schools

Table 20 and Figure 8 present the critical path to reopening the 15 of 16 schools in the county (all except Big Pine Charter, which had a different type of critical path and is discussed in a separate section below). These opened between September 25 and October 2, 2017 on a staggered basis—approximately 15 to 22 days after the disaster. Teachers reported back to schools two school days prior to opening. This was primarily driven by the communities being ready to go back rather than repairing the condition of the schools themselves as the damage was relatively minor. Upon opening, schools were almost at normal operations with just a few rooms closed in some buildings (because of roof flooding). The exception was athletics as some fields were closed for quite some time (months or more).

Table 20. Critical path to 15 (of 16) schools opening

#	Activity	Timing / Duration	Notes
1	Hurricane Irma hit	Day 0 (September 10)	Hurricane Irma hit Little Torch Key Saturday, September 9, 2017 through September 10, 2017 (Day 0).
2	Water generally restored (mostly non-potable at this point)	Day 5 (6 days)	The vast majority of the Keys had 24/7 or rotating non-potable water at this point, which was a major driver in the decision to let people back on the island.
3	Residents and staff return	Day 6 to Day 7 (about a day or two)	On September 16 residents returned all the way down to Marathon, FL. On September 17 residents could return to all the Keys.
4	Formal assessment	Day 8 and part of Day 9 (1.5 days)	Occurred once all maintenance staff were on the island.
5	Principals and Superintendent announce reopenings with feedback from community	Day 9 announcement	Monroe County used staggered opening dates of September 25, September 27, and October 2. This decision was based on feedback from and coordination with staff and families associated with each school. The schools wanted to balance out the positive of getting students back in school with enough time for families to focus on and deal with issues at their homes.
6	Give time for families and staff deal with issues at home	Approximately 6 to 13 days Varies by school system	Staff and families dealt with issues at their homes to better prepare and be ready for school.
7	Schools open	Day 15 (earliest) Day 22 (latest)	Upper Keys opened on September 25. Key West Schools opened September 27. Middle Keys schools opened October 2.

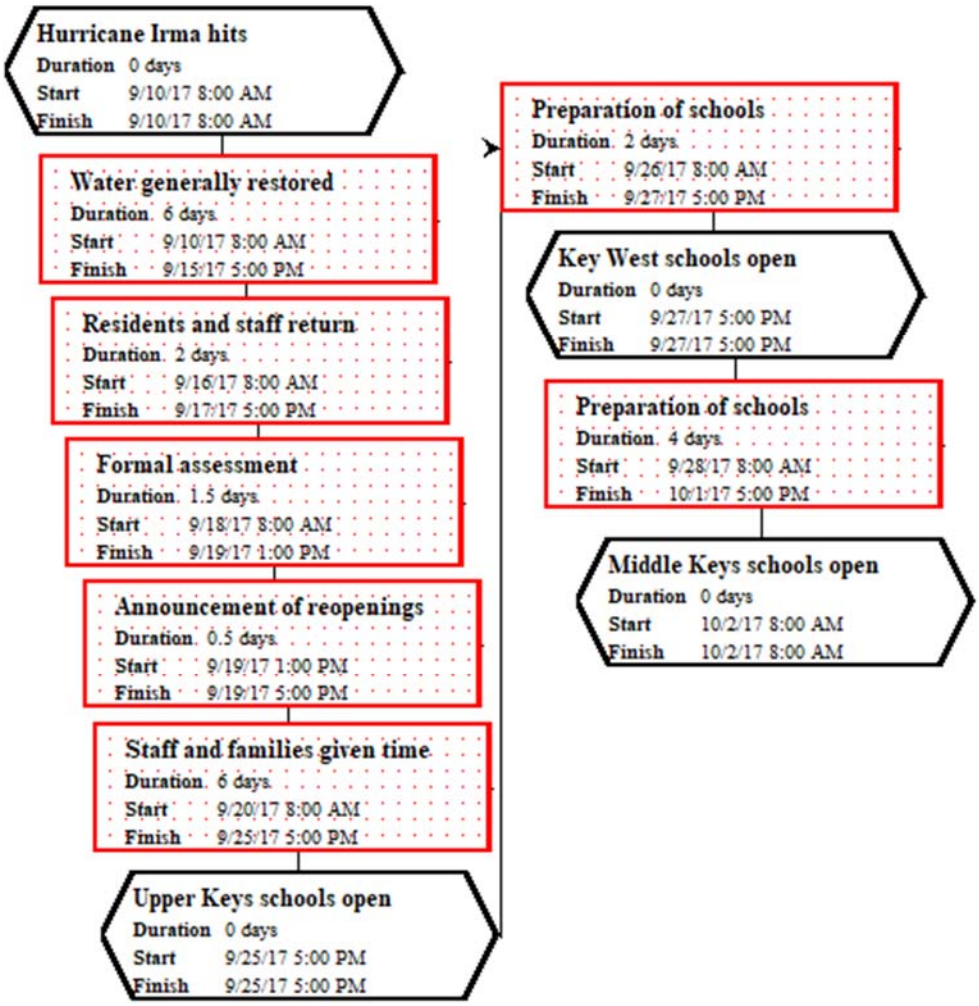


Figure 8. Critical path network diagram for 15 of 16 schools opening

While the critical path to opening included the decision to give families time to recover before they would be ready to go back to school (Activities #5 and #6 in Table 20), there was a different sequence of activities that followed (branched off from) Activity #4 in Table 20, which were on the near-critical path. Table 21 presents another path to recovery that includes some activities shared with the critical path (#1-4) and a few activities on the near-critical path (#5-8). There was a little slack for these activities (#5-8 in Table 21) to be done for the group of 15 schools.

Table 21. Near critical path to 15 of 16 schools reopening

#	Activity	Timing / Duration	Notes
1	Hurricane Irma hit	Day 0 (September 10)	Hurricane Irma hit Little Torch Key Saturday, September 9, 2017 through September 10, 2017 (Day 0).
2	Water generally restored (mostly non-potable at this point)	Day 5 (6 days)	The vast majority of the Keys had 24/7 or rotating non-potable water at this point, which was a major driver in the decision to let people back on the island.
3	Residents and staff return	Day 6 to Day 7 (about a day or two)	On September 16 residents returned all the way down to Marathon. On September 17 residents could return to all the Keys.
4	Formal assessment	Day 8 and part of Day 9 (1.5 days)	Occurred once all maintenance staff were on the island.
5*	Give staff opportunity to take care of issues with homes	Several days	This is where most of the "slack" was in the critical path. Almost all staff were able to come back 2 school days prior to school starting.
6*	Staff return to school to prepare	Duration: 2 days Occurred 2 school days prior to opening date	Staff returned to all schools for two full school days prior to opening to prepare
7*	Bus drivers practice routes	Duration: 1 day Occurred prior to school opening	Bus drivers practiced routes to look for any issues with pick-up points.
8*	Communicate bus route updates	Duration: a few hours Occurred prior to school opening	Added one route from Key West to Sugarloaf school for displaced families. This route continued the full school year. Moved a few spots slightly to avoid debris.
9	Schools open	Day 15 (earliest) Day 22 (latest)	Upper Keys opened on September 25. Key West Schools opened September 27. Middle Keys schools opened October 2.

* Near-critical path activities

Other near-critical path activities included:

1) **Internet restoration:** School was going to open regardless, but this happened close to the beginning of school in some places.
2) **Power restoration:** A request to prioritize power restoration from one school was needed to accelerate this. If it had not been accelerated, power restoration would have been on the critical path.
3) **Roof repair for known leaks:** The assessments missed a few leaks, but these repairs were generally relatively minor and did not contribute to the critical path.

Critical Path to Opening Big Pine Charter School

Big Pine Charter School was the only school of the 16 to be flooded and sustained the most damage of all schools. This school had a different critical path to recovery that was at least as driven by repairs as giving the chance for the community and staff to deal with issues at home, which was a primary driver of the critical path for the other 15 schools.

Table 22. Critical path to Big Pine Charter School reopening on a partially operational basis

#	Activity	Timing / Duration	Notes
1	Hurricane Irma hit	Day 0 (September 10)	Hurricane Irma hit Little Torch Key Saturday, September 9, 2017 through September 10, 2017 (Day 0).
2	Water generally restored (mostly non-potable at this point)	Day 5 (6 days)	The vast majority of the Keys had 24/7 or rotating non-potable water at this point, which was a major driver in the decision to let people back on the island.
3	Residents and staff return	Day 6 to Day 7 (about a day or two)	On September 16 residents returned all the way down to Marathon. On September 17 residents could return to all the Keys.
4	Formal assessment	Day 8 and part of Day 9 (1.5 days)	Occurred once all maintenance staff were on the island.
5	Repairs to make school partially operational	Day 9 to Day 21 (13 days)	Involved fixing the ramp to allow students to get to undamaged second floor classrooms and minor repairs in the cafeteria as that was used for class space with damage to other buildings.
6	Big Pine Charter School opens (partial operations)	October 2, 2017 Day 22	K-1 was moved to another building (church) while grades 2-5 were either in upstairs classrooms or the cafeteria because all five first floor classrooms were flooded, and damaged and all four modular trailers were completely destroyed by flooding.

In addition to these above critical path activities, one near-critical path activity was identified:

1) **Giving time for families and staff deal with issues at home** may have been part of either a near-critical path or a second critical path (same path as Table 1). The school was planning on opening on October 2 (later than most other schools because damage was more extensive to families' houses in this area) even if repairs had been done earlier to give families and staff enough time to deal with issues at home in this particularly damaged area of the Middle Keys. There is a case that Big Pine Charter could have had two critical paths with the same timeline (Table 1 and Table 3).

Critical Path to Big Pine Charter School Operating Under Close to Normal Operations

Following school opening on October 2, 2017, there was a period of planning and discussion about the future of the school and whether this opportunity should be used for a more complete replacement/renovation in lieu of just repairing storm damage. Ultimately, it was decided to repair it to get the school ready for state testing in April 2018. The decision process was part of the critical path as well as the ensuing repairs. The critical path to Big Pine Charter School returning to near-normal operations is presented in Table 23 and Figure 9. This path shared the same critical path as getting the school to open on a partial basis (same as Table 22) as the maintenance team and principal dealt with first getting the school open before turning to assess longer term decisions.

Table 23. Critical path to Big Pine Charter School reopening with more normal operations

#	Activity	Timing / Duration	Notes
1	Hurricane Irma hit	Day 0 (September 10)	Hurricane Irma hit Little Torch Key Saturday, September 9, 2017 through September 10, 2017 (Day 0).
2	Water generally restored (mostly non-potable at this point)	Day 5 (6 days)	The vast majority of the Keys had 24/7 or rotating non-potable water at this point, which was a major driver in the decision to let people back on the island.
3	Residents and staff return	Day 6 to Day 7 (about a day or two)	On September 16 residents returned all the way down to Marathon. On September 17 residents could return to all the Keys.
4	Formal assessment	Day 8 and part of Day 9 (1.5 days)	Occurred once all maintenance staff were on the island.
5	Repairs to make school partially operational	Day 9 to Day 21 (13 days)	Involved fixing the ramp to allow students to get to undamaged second floor classrooms and minor repairs in the cafeteria as that was used for class space with damage to other buildings.
6	Big Pine Charter School opens (partial operations)	October 2, 2017 Day 22	K-1 was moved to another building (church) while grades 2-5 were either in upstairs classrooms or the cafeteria because all five first floor classrooms were flooded, and damaged and all four modular trailers were completely destroyed by flooding.
7	Determine decision about whether to replace/renovate or fix school	About a month	Ultimately it was decided to fix flooded first floor classrooms and replace modular trailer classrooms.
8	Perform repairs to fix school	Several months	These focused on what needed to be done to get the K-1 students back and allow for a better testing environment (out of the cafeteria). This included repairs to four of five flooded first-floor classrooms (the fifth one was too damaged to repair in time) and installing new modular trailers. This used a mix of in-house and contracted labor.
9	Big Pine Charter School opens more classrooms	April 2018	All 80 students were back in school and more normal operations ensued.

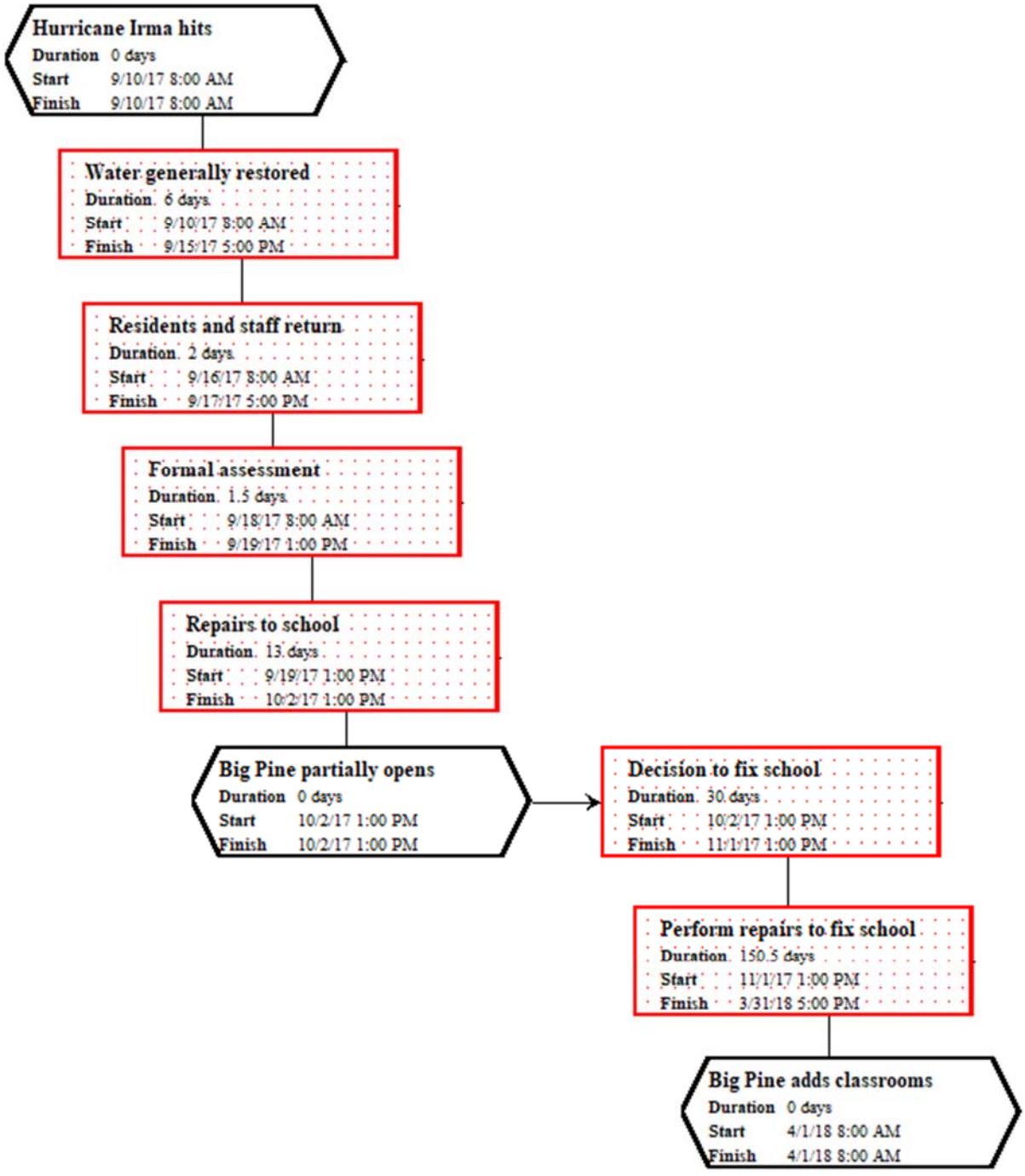


Figure 9. Critical path network diagram for reopening Big Pine Charter School

B-3: Houston Independent School District (Hurricane Harvey)

School Information

- **Schools**: 280
- **Combined Enrollment:** Approximately 215,000 students; about 4,000 left after Harvey.
- **Damage:**
  - 264 schools had minor or no damage and opened up within two weeks (September 11, 2017)
  - 13-17 schools had moderate damage and opened up day-by-day over the course of the following weeks.
  - 1 school (Liberty) was consolidated with another school.
  - 4 schools sustained extreme damage and are being rebuilt. These were older schools located in or on the boundary of the floodplain. The new buildings will be elevated above the floodplain. The students moved to old (unused) school buildings that the district still had on hand.
  - Overall, about $130 million to rebuild the four schools and $50 million to repair the rest of the other schools combined.
- **Information Source:** Senior Manager, Risk Management

Key Findings

What sped up the critical path to recovery?

- Pre-storm preparations: Buttoned up the roof; removed computers from floors and unplugged electronics; removed and secured loose items from the grounds, topped off vehicles with fuel, moved buses to higher ground and in strategic and decentralized locations so they can help with rescues, tested and topped off generators.
- Each school had an assigned "Plan Operator" who lived near the school and performed the initial assessment and turned on the boiler and HVAC as soon as the flood water receded.
- They had established zones within the district to prioritize and assign recovery and clean up tasks.
- They had already developed a Hurricane Preparedness Guide, which helped identify and assign tasks—both a district-wide plan and specialized plans (i.e., one for food services, one for transportation). This included check lists with activities for before during and after the event.
- They expanded their capacity to deal with the biggest obstacle—indoor air quality checks—this included hiring a contractor to do some of the tests (who in turn hired additional subcontractors), and Houston's internal staff worked much longer days to get schools ready for opening.

What slowed down the critical path to recovery?

- Large number of schools compared to the limited number of technicians that could perform air quality testing.

Recommendations for what else could be done to help with potential future events?

- Solicit bids in advance for all necessary contract work / trades associated with disaster recovery (e.g., plumbers, contractors, electricians, carpenters, air quality monitoring technicians, debris clean up). This is something Houston has now implemented post Harvey.
- Use drone services for preliminary assessments. This could help provide access to schools that are not accessible by road (i.e., trees down or flood waters blocking access). Drones can also assess areas of schools like roofs that may not easily be accessible by a single plan operator / assessment personnel.
- Ensure all paperwork is setup in advance to be FEMA compliant. HISD found paperwork acceptable by FEMA is acceptable by their private insurance company.
- Offer parametric insurance to help keep students in the region. This would be bought by the school system and provide resources for families to find alternative housing within their school district and stay in the same school district while their house is being repaired. This would keep the funding coming in from the state (which is tied to enrollment) and help ensure no layoffs are required because of reduced funding to the district.

Critical Path to Recovery Details

Hurricane Harvey impacted the Houston Independent School District, primarily as a rain and flooding event. Rains began August 25, 2017 with the heaviest rain falling on August 26 and 27 (Saturday and Sunday). We are listing August 27, 2017 as "Day 0" in the tables below. The first day of school was planned for Monday, August 28 but was moved back to Monday, September 11 to allow for a critical mass of schools to be ready to start. A handful of schools (about 13-17) opened up on a day-by-day basis over the next couple of weeks. The critical path to reopening 264 of 280 schools is detailed in Table 24 and illustrated in Figure 10.

Table 24. Critical path to reopening 264 of 280 schools

#	Activity	Timing / Duration	Notes
1	Hurricane Harvey hit	Day 0	Hurricane Harvey hit Houston, TX August 25 to 27 with the heaviest rains falling on August 26 and 27.
2	Preliminary damage assessment	Day 1 (about one day)	This activity took about a day but not all designated Plan Operators were able to make it in on August 28. This activity occurred several days later for areas where flooding did not recede as quickly, or roads were still blocked.
3	Indoor air quality testing	Day 2 – Day 14	This only takes a matter of a day or so to perform testing and get results at the individual school level. The issue here is the number of schools that needed to be tested for mold, carbon dioxide, and carbon monoxide and the limited staff to test—it took about two weeks to make it through all the schools that needed air quality testing.
4	Schools Open	Day 15	264 schools opened up on Monday, September 11, 2017. This included schools with no/minor damage; schools that had some flooding, were dried out, cleaned up, and ready to go; and some schools with major damage where students were moved to other buildings.

In addition to the critical path items, here are some near-critical path items:

- **Access (tree clearing and flooded roads).** When looking at the decision to open 264 schools, this item may not have impacted the start date. At the individual school level, some assessments were started later because of no access to the schools. Ultimately, there was a queue to perform air quality testing so schools that were ready for it got it done earlier and these schools impacted by access issues had it done later.
- **Ensuring food supply**. This step occurred after buildings were deemed safe to enter based on air quality testing results. It ended up not being on the critical path as HISD sources and warehouses food internally.
- **Principals and front offices assessing schools.** This occurred after buildings were deemed safe to enter based on air quality testing results. This ended up not being a critical path item for the majority of schools as this was a rather quick task which schools could fit in prior to the set September 11 start date.

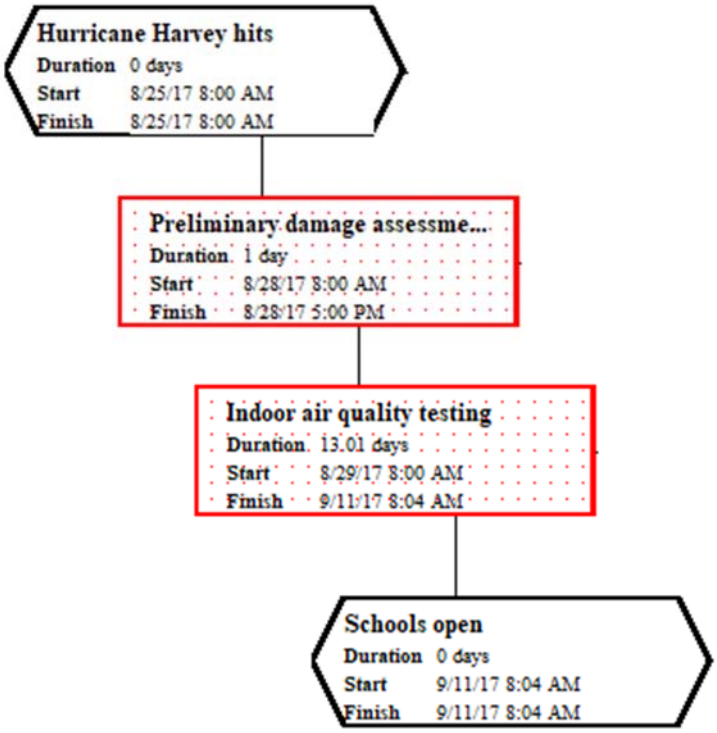


Figure 10. Critical path network diagram for reopening 264 of 280 schools

B-4: Port Aransas Independent School District (Hurricane Harvey)

School Information

- **Schools:** 3 schools (K-5, 6-8, 9-12) all on the same site.
- **Combined Enrollment:** 525 students before storm; 438 when schools opened on October 16; 480 by January 2018; and 504 (96% of pre-storm levels) 1-year later. Prior to storm 10-15% of students were out-of-district transfers (primarily from Corpus Christi), and currently 20-25% are out-of-district transfers.
- **Damage:**
  - The Middle School sustained the most damage: 3 feet of water, severe wind damage, and was hit hardest by the bay-side storm surge.
  - The High School was flooded from a couple inches to 18 inches.
  - The Elementary school had wet floors and carpets with the least flooding.
  - The roofs of all three schools were damaged and had to be replaced.
- **Information Source:** School Superintendent.

Key Findings

Recovery milestones include opening school in temporary modules after about seven weeks and reopening the Elementary and High School after about four months and the Middle School the following school year.

What sped up the critical path to recovery?

- The school system had an agreement in place prior to the event with a disaster recovery contractor. The contractor arrived on site on Day 3 to perform remediation and reconstruction of all three schools.
- The disaster recovery contractor had exclusive contracts in place with plumbers, electricians, and other trades, so the school district was not impacted by the limited availability of these trades.
- Port Aransas had decided to renovate their schools prior to Harvey and had already picked out tiles and roofing materials. Work had begun at the high school prior to the storm and was planned to begin at the other two schools in the near future.
- The Superintendent had daily 9 am meetings with the disaster recovery contractor so decisions could be made rapidly. This was important given the lack of phone and internet for nearly one month.
- Other schools helped with supplies such as books, bookshelves, desks.

- Nearby Corpus Christi had electricity, water, and communication much sooner. This allowed people to to make the 30 minute drive at night to find a place to sleep, use the internet, and perform tasks that could not be done on site at the schools.
- San Antonio provided buses. Because of the rapid intensification of the storm in the 24 hours before landfall, all of Port Aransas' buses were flooded and needed significant repairs.

What slowed down the critical path to recovery?

- The FEMA grant application and oversight processes took considerable time and energy. This included confusion in how to file paperwork, finding very old records, and needing to be around to observe FEMA's assessments and measurements. Going through this process ultimately helped the school financially but diverted attention from recovery efforts.
- Issues on where to place temporary modular buildings. Almost the entire island is a flood zone. Thus, there were difficult decisions about where to place the temporary units.
- There was very little time to prepare before landfall. The storm intensified so quickly that there was only 11 hours to implement the 5-day plan. There was no opportunity to move the buses to Corpus Christi. Some shuttering of window was done, and only the very essentials were packed up and taken.

Recommendations for what else could be done to help with potential future events?

- Be provided with a recovery officer who knows how to deal with FEMA and their processes.
- Increase training for FEMA recovery personnel.
- Simplify the FEMA grant application and oversight processes.

Critical Path to Recovery Details

Hurricane Harvey impacted the Port Aransas Independent School District (PAISD) with Category 4 winds and flooding from bayside storm surge. Schools had been opened for 3.5 days in the new school year when Harvey hit Port Aransas. After a preliminary damage assessment, the school system determined they would not be able to open the damaged schools until after New Year's. Thus, they decided to bring in portable modular units for temporary classroom space. All three schools were shut down for 7 weeks (while students enrolled in out-of-district schools—one K-8 charter school at the south side of the island and one school in Corpus Christi) and opened back up on October 16, 2017 with temporary units. PAISD decided on the October 16 opening date on September 18, 2017 based on estimates for completion time setting up the temporary units, which is why they made do with only 75 percent of them being setup on October 16. The critical path to all three schools opening back up with portable units is presented in Table 25 and Figure 11.

Table 25. Critical path to schools reopening with temporary modular units

#	Activity	Timing / Duration	Notes
1	Hurricane Harvey hit	Day 0 (August 25)	Hurricane Harvey hit Port Aransas, TX August 25, 2017.
2	Wait to access island	Day 1-2 (2 days)	Residents were not allowed back on the island and nobody could safely make an assessment.
3	Preliminary damage assessment	Day 3-6 August 28-31 (4 days)	Disaster recovery contractor arrived on site on August 28, 2017 to perform a preliminary assessment. At this time, they determined that none of the schools could be reconstructed before Christmas.
4	Determine best path forward to open schools	Day 7-9 Sept 1 - 3 (3 days)	PAISD decided they did not want their students out of the district until Christmas or later and decided to order temporary portable classrooms.
5	Portable classrooms ordered and setup	Day 10-49 Sept 4 – Oct 13 (40 days)	50% of the units were in by October 9, 75% of the units were in by October 16 (which was deemed enough to start classes), 100% of the units were in by October 23.
6	Inspection of portables	Day 50 1 day October 14	The inspectors were very flexible to make sure these got done quickly as schools were a priority for the city to open.
7	Teachers setup classrooms	Day 51 1 day October 15	Assessment of whether supplies were usable (desks, bookshelves, etc.) was done while portables were being setup. This included final setup after portables were setup and inspected. Corpus Christi brought books, materials, bookshelves, etc. as much of Port Aransas equipment was unusable because of salt water damage. Some teachers set up as early as October 8, but many had to wait until the day before school because their temporary units were not yet ready.
8	Schools began in portable units	Day 52 (October 16, 2017)	The final 25% of portables were not setup for another week or so. They still opened school by combining classrooms and holding classes outside as needed for middle school and high school students.

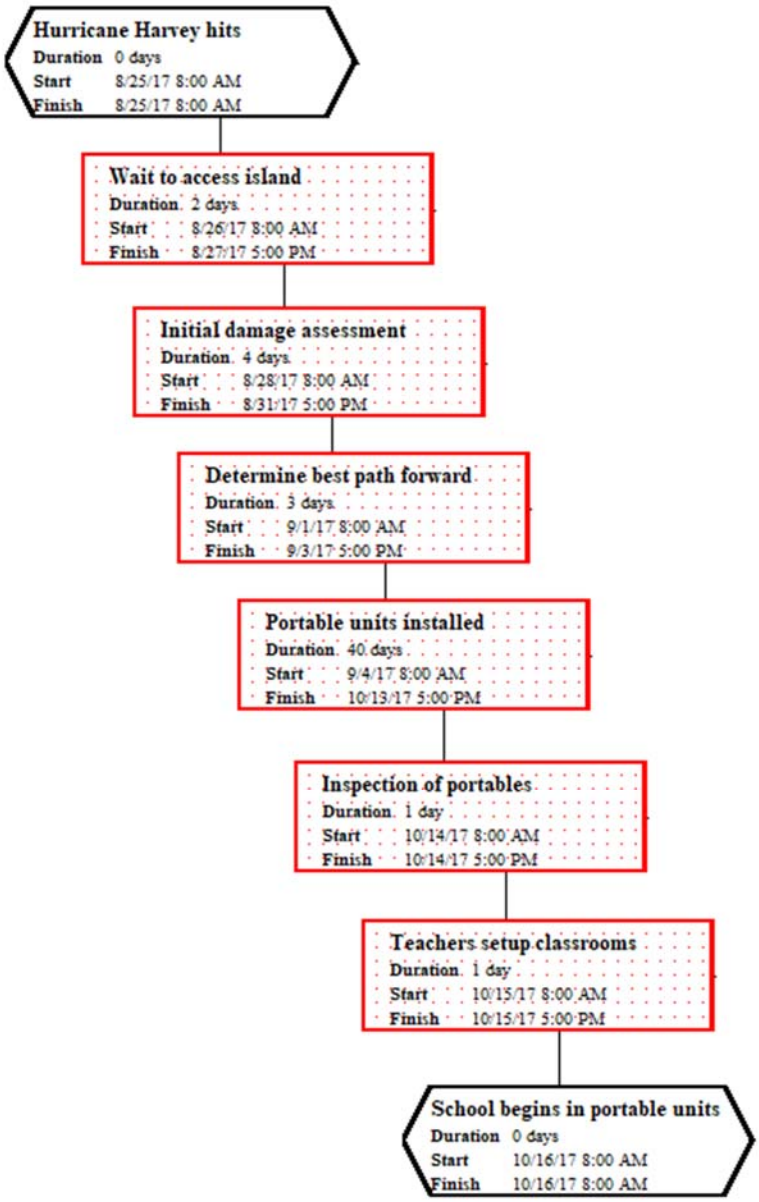


Figure 11. Critical path network diagram for reopening schools with temporary modular units

The Middle School, Elementary School, and High School had a similar path; however, the path of the Middle School was much longer because of more extensive damage. **Table 26** and Figure 12 show the critical path to recovery for the high school and elementary school. **Table 27** and Figure 13 show the critical path to recovery for the middle school.

Table 26. Critical path to elementary and high schools reopening (after reconstruction)

#	Activity	Timing / Duration	Notes
1	Hurricane Harvey hit	Day 0 (August 25)	Hurricane Harvey hit Port Aransas, TX August 25, 2017.
2	Wait to access island	Day 1-2 (2 days)	Residents were not allowed back on the island and nobody could safely make an assessment.
3	Preliminary damage assessment	Day 3-6 August 28-31 (4 days)	Disaster recovery contractor arrived on site on August 28, 2017 to perform a preliminary assessment.
4	Rebuild versus repair decision	Day 6 (<1 hour)	Port Aransas had planned renovations prior to the hurricane; thus, they made this decision easily after the preliminary damage assessment. This was further sped up because they had already picked out tiling and roofing as they had recently completed renovations at the high school.
5	Remediation	Day 7-20 (two weeks)	Disaster recovery contractor started some of this during the preliminary damage assessment, and this generally included drying and cleaning the schools to prevent mold.
6	Construction and repairs	Day 21-131 (111 days)	Disaster recovery contractor served as the contractor and project manager. This process was sped up by daily 9am meetings with the school superintendent (because other communication was down). It was also sped up because the disaster recovery contractor had exclusive contracts with plumbers and electricians to prevent the process from being delayed accordingly.
7	Teachers setup classrooms	Day 132-136 January 3-7 (about 5 days)	Teachers set up rooms over winter break as contractor had recently finished construction. This included moving a lot of supplies from portable units to permanent buildings.
8	High school and elementary school reopen	Approximately Day 136 January 8, 2018	

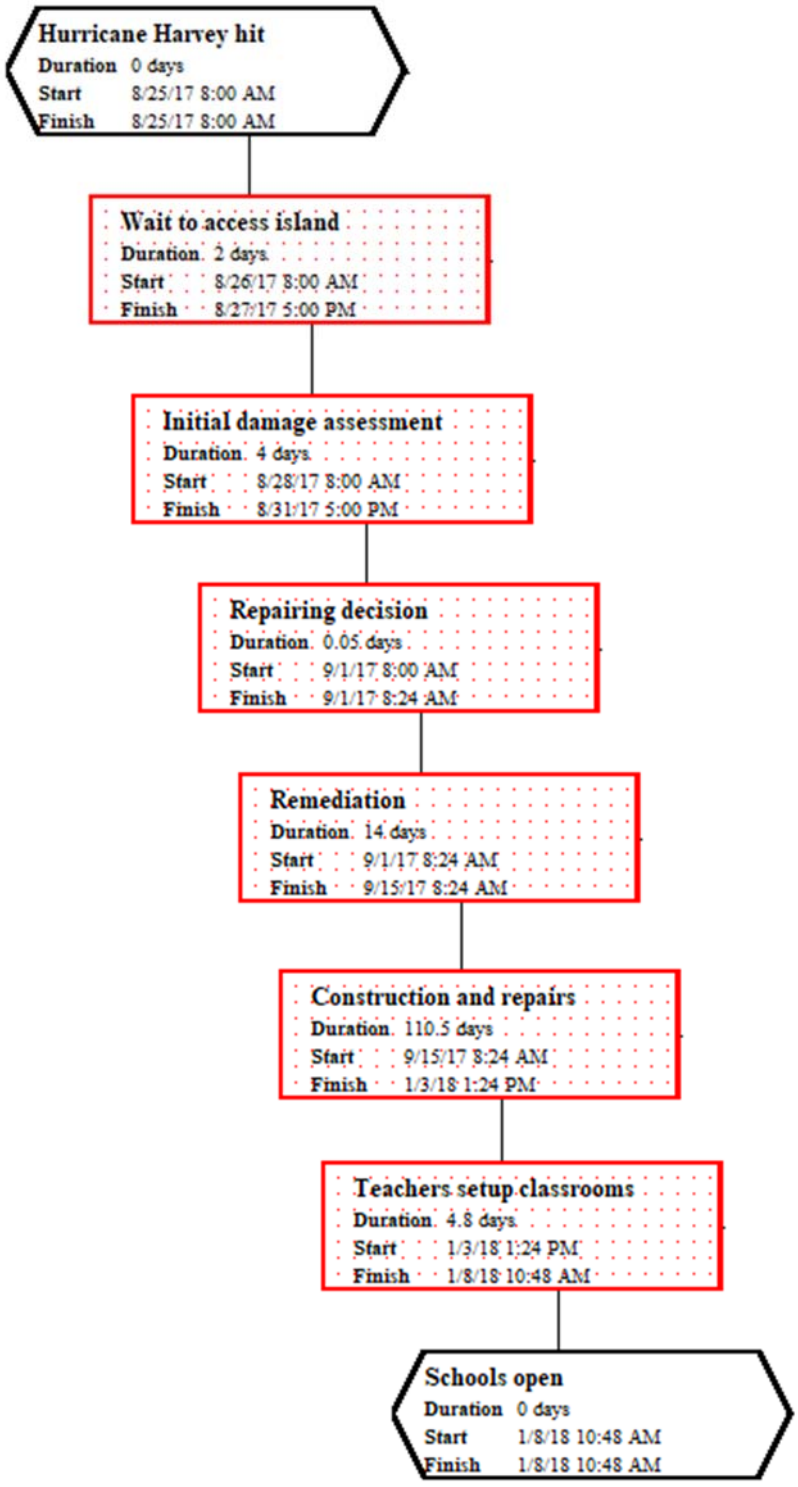


Figure 12. Critical path network diagram for reopening elementary and high schools

Table 27. Critical path to middle school reopening (after reconstruction)

#	Activity	Timing / Duration	Notes
1	Hurricane Harvey hit	Day 0 (August 25)	Hurricane Harvey hit Port Aransas, TX August 25, 2017.
2	Wait to access island	Day 1-2 (2 days)	Residents were not allowed back on the island and nobody could safely make an assessment.
3	Preliminary damage assessment	Day 3-6 August 28-31 (4 days)	Disaster recovery contractor arrived on site on August 28, 2017 to perform a preliminary assessment.
3	Rebuild versus repair decision	Day 6 (<1 hour)	Port Aransas planned renovations prior to the hurricane; thus, they made this decision easily after the preliminary damage assessment. This was further sped up because they had already picked out tiling and roofing as they had recently completed renovations at the high school.
4	Remediation	Day 7-48 (six weeks)	Disaster recovery contractor started some of this during the preliminary damage assessment, and this generally included drying, cleaning, and removing dead fish and animals as the Middle School faced the bay side storm surge and was the most damaged of the three schools.
5	Construction and repairs	Day 49-344 (296 days)	Disaster recovery contractor served as the contractor and project manager. This process was sped up by daily 9am meetings with the school superintendent (because other communication was down). It was also sped up because the disaster recovery contractor had exclusive contracts with plumbers and electricians to prevent the process from being delayed accordingly. Construction may have had some slack because of targeting start date of August 20, 2018 (after summer vacation).
6	Setup classrooms and other rooms	Day 345-359 (15 days)	Teachers set up rooms toward the end of summer break as contractor had recently finished construction.
7	Middle school opens	Day 360 August 20, 2018	The Middle School was opened on the first day of school for the 2018-2019 school year. There may have been some slack in the recovery timeline as this was the first day of scheduled school

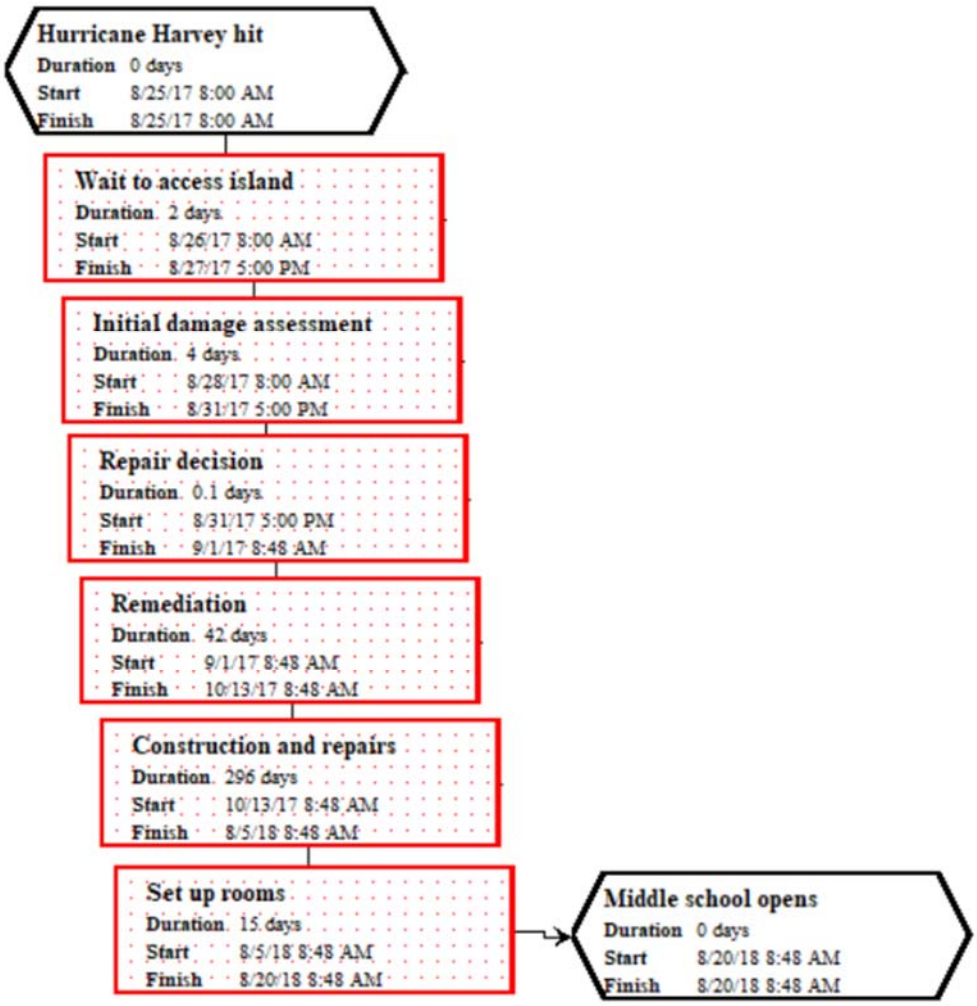


Figure 13. Critical path network diagram for opening the middle school after reconstruction

B-5: Tuscaloosa City School District (2011 Tornado)

School Information

- **Schools:** Two schools (three buildings) impacted by tornado out of 23 total schools (2011) serving grades K-12 in the Tuscaloosa City School District.
- **Combined Enrollment:** 850 students in impacted schools (~10,000 in district)
- **Damage:** Two schools were hit (three buildings total): Alberta Elementary and University Place Elementary and Middle School. The schools that were hit had a total enrollment of about 850 students.
- **Information Source:** Superintendent of Tuscaloosa City Schools and Executive Director of Human Resources and Operations.

Key Findings

- Advanced warnings and coordination with Tuscaloosa County's Emergency Management Agency enabled cancellation of Tuscaloosa City and County Schools (two separate districts). They based this decision on a forecast of severe weather.
- Interagency collaboration between the city and county was key to speedy damage assessments, schools reopening, and rebuilding.
- Tuscaloosa City Schools had enough "slack" in the system (capacity at other schools) to safely send students to other schools in the district without need for temporary modules or other potential delays.
- The School District authorized funds to start repairing University Place Elementary and Middle School and coordinated with FEMA after the fact for reimbursement.

What sped up the critical path to recovery?

- School administrators and superintendent's office had LINK walkie-talkies that enabled immediate communication, despite cell phones being out of service and power outages.
- There were no financing slowdowns. The district coordinated with insurers and FEMA after the fact for reimbursement.
- Extra capacity allowed the district to send students to other undamaged schools within the district.

What slowed down the critical path to recovery?

- Clearing debris from roads.
- Lack of communications (phones and outages). In some areas, it was necessary to knock on doors to relay logistics for the new school assignment for students zoned for the damaged schools. This could have been quicker with communications up.

Recommendations for what else could be done to help with potential future events?

- Establish interagency emergency communications protocol.

- Establish roles and responsibilities to entities and individuals.
- Establish emergency response plan.
- Have working knowledge of school district and building capacity.

Critical Path to Recovery Details

The tornado damaged two schools. The tornado completely destroyed Alberta Elementary School and caused substantial damage to the University Place Elementary and Middle School (two buildings). When the tornado hit (April 27), there were only three weeks left in the school year, sports were about wrapped up, and there were not many extracurricular activities remaining. Additionally, Tuscaloosa City Schools had extra capacity in many of their 20 undamaged schools within the district, eliminating any urgency to quickly rebuild or repair Alberta Elementary and University Place Elementary and Middle School. These two factors gave city and school officials time to make a conscious effort to consider the future of the district without delaying students' return to school. During this time, officials decided to repair University Place Elementary and Middle School and convert it to a K-5 STEAM school. The decision to completely rebuild Alberta was a delayed comparatively, as the district decided to convert Alberta Elementary to The Alberta School of Performing Arts (TASPA), a K-8 school. A detailed critical path to recovery for the reopening of University Place Elementary (about 44 months after the tornado) and TASPA (about 51 months after the tornado) is not provided as these processes followed a more conventional community planning and implementation timeline. In Table 28 and Figure 14, we present the critical path to returning to school immediately after the tornado.

Table 28. Critical path to opening schools

#	Activity	Timing / Duration	Notes
1	School is cancelled due to severe weather forecasts Wednesday April 27, 2011	Day 0	Tuscaloosa City Schools had enough advanced warning (of severe weather) to cancel schools the day of the 2011 tornado.
2	Tuscaloosa Tornado touches down April 27, 2011	Day 0	Tornado hit touched down just after 5:00pm and was approximately 1-mile wide and traveled approximately 5.9 miles. The tornado hit two schools (three buildings) in the Tuscaloosa City School district, completely destroying one (building) and damaging the other (with two buildings)
3	Conduct damage assessment	A few hours	That evening, administrators that were able to travel conducted damage assessments and communicated via LINK walkie-talkies.
4	City clears debris from roads	Day 0 – Day 3 (4 days)	Clear roads were indicated to be a significant delay to the recovery process. Both interviewees indicated that school could have been held sooner if the debris did not delay the recovery process.
5	Disseminate School Opening and Revised Location Information	Day 4 – Day 6 (3 days)	By day 3, district impacted schools had made contact with about 95% of students and by day 4 announced the opening for May 4 (day 7). The CLT, teachers, and volunteers formed door knocking committees to go to every neighborhood and hand out flyers with important information. Approximately 850 students from the damaged or destroyed schools were sent to other schools in the district. Tuscaloosa City Schools offered bus services to bring each student to their revised location, regardless of where they needed to be picked up.
6	Students return to school Wednesday, May 4, 2011	Day 7	Tuscaloosa City Schools reopened, with strong attendance and about 850 students in temporary locations within the district for the remaining three weeks of the school year.

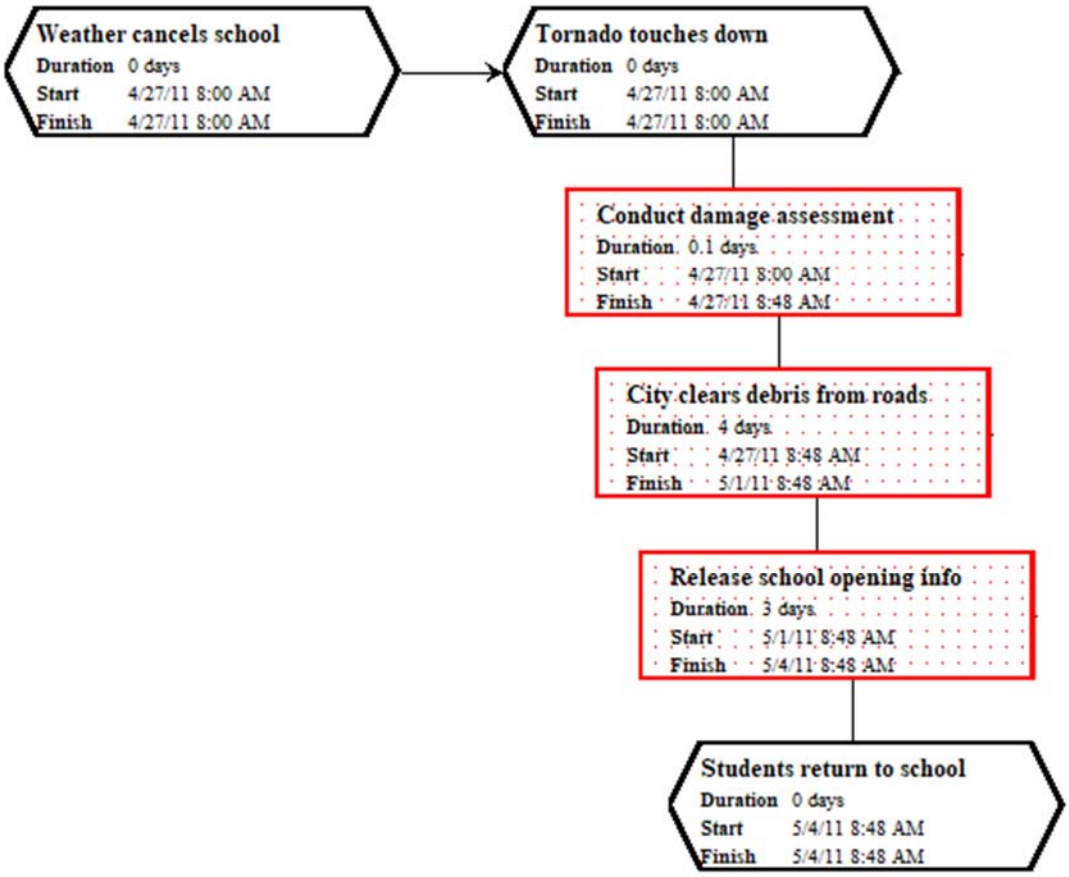


Figure 14. Critical path network diagram for reopening schools

Near-Critical Path Items:

- On Thursday April 28 (Day 1), the Central Leadership Team [CLT] (school officials, all principals and assistant principals) met to discuss damage to schools, conducted staff calling tree to assess staff needs and assigned coordination roles for the recovery process (who will coordinate with DOT, County EMA, etc.). This took about two days whereas the debris cleanup (critical path) took about four days.
- For about three or four days, staff prepared undamaged buildings to accommodate extra classroom space. Teachers and community volunteers worked tirelessly to prepare new classroom space, transfer supplies, and manage classroom needs and donations. This occurred while the City was clearing debris and outreach was being done to disseminate information to parents.

B-6: School Recovery in Waterbury, Vermont (Hurricane Irene)

School Information

- **School Name:** Thatcher Brook Primary School (Waterbury, Duxbury). One of several schools that feeds into Harwood High School (Harwood Supervisory Union).
- **Damage:** The school was not physically damaged but was closed down for about a week after the storm.
- **Employees:** This was the same before and after the storm.
- **Students:** This was the same before and after the storm.
- **Source of Information:** Former Principal

Key Findings

What sped up the critical path to recovery?

- The school helped organize volunteers to help clear out and clean up houses, which helped ensure the community and residents were in a better place to start going back to school.
- The school is sited on a hill well above the floodplain.

Critical Path to Recovery Details

Hurricane Irene was primarily a rain event by the time it made it to Northern Vermont on Sunday, August 28, 2011. Saturated grounds from a wet summer caused more water to run into the river. Below, we present the critical path of the school reopening.

Table 29 and Figure 15 show the critical path to students returning to school. As there was no damage to the school, the recovery was quick. School was set to open on Wednesday, August 31, but did not start until Tuesday, September 6, 2011. This was primarily driven by the school initially serving as a shelter and then as a focal point for organizing community recovery efforts.

Table 29. Critical path to students returning to school

#	Activity	Duration	Notes
1	Irene hits on Sunday, August 28, 2011	Day 0	A choke point in the river caused the river to rise several feet above the 100-year flood plain. There was no damage to the school, but the community was impacted with about five to eight feet of flooding for about 200 homes and several businesses. A large state office complex was also flooded.
2	School opens as shelter	Day 0-1 (Sunday Night to Monday) (1 day)	This caused the in-service day for teachers (Monday) to be cancelled.
3	Held meetings with decision makers	Day 1-2 (2 days)	These meetings continued daily and included the principal, fire chief, and other key decision makers in the town.
4	Relocate displace town hall offices to school and organize volunteers	Day 3-4 (2 days)	On Wednesday and Thursday, the school helped facilitate volunteering by organizing groups to help with clearing and cleaning homes and businesses in the impacted areas.
5	Decision made to open schools the day after Labor Day.	Around Day 5	After a couple days of assessing the community damages, the district decided to start classes on the Tuesday after Labor Day (Day 9).
6	School opens	Day 9	School opens. The only deviation from normal operations included a few displaced students and the use of two extra classrooms (typically dedicated for tutoring) by town office personnel for about two months (at which time they moved to the Fire Station).

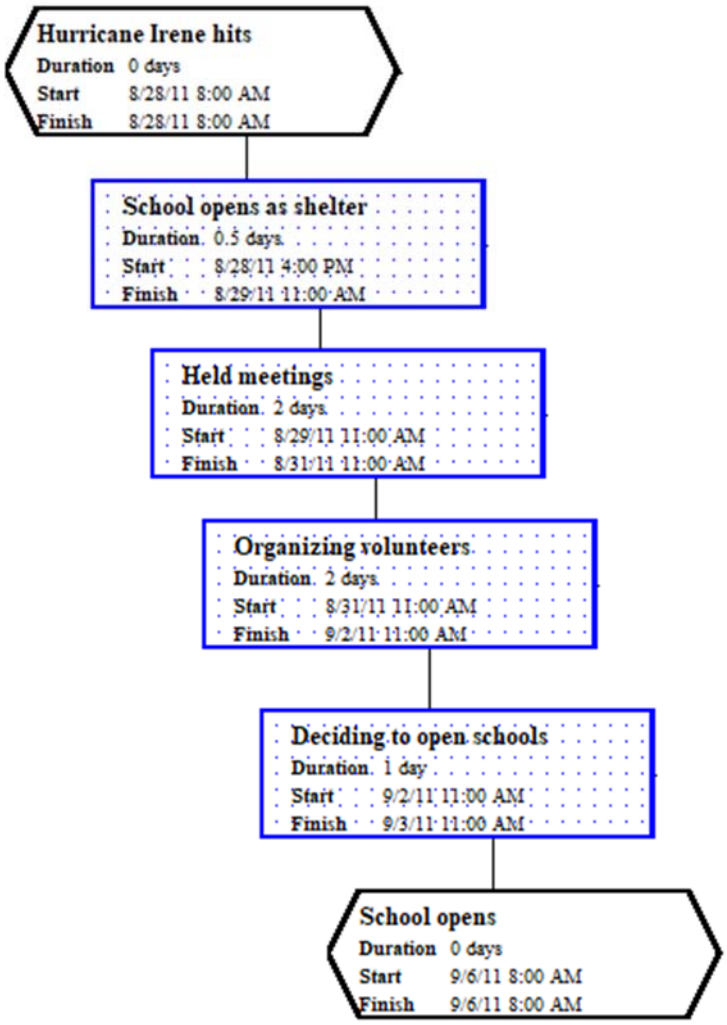


Figure 15. Critical path network diagram for reopening schools

B-7: St. Thomas Schools (Hurricanes Irma and Maria)

School Information

- **Note:** The project team met with a representative from the STTJ school district, however, the meeting was cut short due to interviewee illness, and we were unable to schedule a follow-up discussion. The project team has used information from the abbreviated interview and independent research to fill out as much of this case study as possible. No network diagrams have been made for St. Thomas schools due to several uncertainties with dates and durations of critical path activities.
- **Schools:** The project team focused on St. Thomas schools, which are part of the St. Thomas-St. John [STTJ] district. The St. Croix [STX] district had a different timeline/ experience.
- **Combined Enrollment:** During the 2017-2018 school year, across both the STTJ and St. Croix (STX) districts, there were roughly 27 school buildings with a total enrollment of just over 10,850 students.[1]
- **Damage:** The extent of damage varied depending on the location of the school and construction of the school
- **Information Source:** Director of Operations for Department of Education STTJ District

Key Findings

What sped up the critical path to recovery?

- USACE and FEMA provided assistance which sped up the installation of generators in the schools. The students were able to return to school after the procurement and installation of these generators.

What slowed down the critical path to recovery?

- STTJ had to wait for USACE to procure and install generators.

Recommendations for what else could be done to help with potential future events?

- STTJ is applying for grants to purchase their own generators.

Critical Path to Recovery Details

The critical path for the majority for USVI schools opening is presented in Table 30.

[1] https://www.vide.vi/data-reporting/public-data/2-uncategorised/1775-2017-2031.html

Table 30. Critical path to students returning to school on shift-based schedule

#	Activity	Timing / Duration	Notes
1	Hurricane Irma hits September 6, 2017	Day 0	Hurricane Irma was a category 5 storm that passed over the northern parts of St. John and St. Thomas.
2	Clear major debris and prepare for Maria	Day 0 to Day 14 (14 days)	There were no major restoration actions taken during the time between hurricanes. During this time some of the larger debris was cleared from schools and some preparatory actions were taken to prevent further damages from Maria (i.e., tarping roofs)
3	Hurricane Maria hits September 20, 2017	Day 14	Maria had less of an impact on St. Thomas than Irma. However, much of the island was in such a fragile state following Irma, such that Maria exacerbated existing damages and caused some new damages.
4	Assess damage	Unknown	
5	Clear debris	Unknown	
6	Decide which schools to reopen versus which were destroyed	Unknown	
7	USACE obtain and install generators at minimally damaged schools	Unknown to Day 42	
8	First wave of schools reopen October 19, 2017.	Day 43 (October 19) 44 days	Minimally damaged schools reopened on a somewhat rolling basis as USACE completed installation of generators and upon completing repairs. Not all schools reopened and students attended the open schools in shifts (morning shift and afternoon shift) for the remainder of the 2017-2018 school year.
9	Second wave of schools reopen late October 2017	Day 50 (51 days)	
10	Lockhart Elementary reopens early November 2017	Day 61 (62 days)	Lockhart Elementary was the last of the minimally damaged schools to reopen because it was being used as a temporary shelter.

Near-Critical Path

- Repair schools: Damage to schools was dependent on location. Repairs to schools might have been on the critical path if generator procurement and installation had been completed earlier. A number of STTJ maintenance employees left the island, which may have impacted the repair timeline.
- Practice bus routes (transportation) and prepare classroom: By the time the generators had been procured and installed and the first wave of schools was ready to reopen, debris was cleared from roads, bus routes had been determined, and classrooms were prepared.
- Obtain financing: Many contractors offered to work as volunteers or to be paid after the fact. Payment to contractors is still ongoing. Had contractors not volunteered or agreed to be paid after the fact, financing issues may have slowed down the critical path to reopening schools.

Table 31. Critical path to returning to normal school schedule

#	Activity	Timing / Duration	Notes
1	Hurricane Irma hits September 6, 2017	Day 0	Hurricane Irma was a category 5 storm that passed over the northern parts of St. John and St. Thomas traveling toward the Gulf Coast of Florida.
2	Other activities	Unknown	
3	Receive and install modulars	May/June 2018 to Early September 2018	Modulars were set up in available areas (i.e., Charlotte Amalie HS field) to accommodate student capacity to start the 2018-2019 school year without the shift-based schedule.
4	STTJ students start school year on normal schedule mid to late September 2018	September 19 to September 27 (~13mo)	Students start the 2018-2019 school year on a normal schedule, with no shifts. Some students attending class in temporary modulars.

Appendix C: Business Critical Path Case Studies

- C-1: Long Beach Township, NJ (Hurricane Sandy, 2012): Restaurant
- C-2: Monroe County, FL [Florida Keys] (Hurricane Irma, 2017): Hotel/Resort
- C-3: Houston, TX (Hurricane Harvey, 2017): Restaurant
- C-4: Port Aransas, TX (Hurricane Harvey, 2017): Hotel/Resort
- C-5: Tuscaloosa, AL (2011 Tornado Outbreak): Doughnut House
- C-6: Tuscaloosa, AL (2011 Tornado Outbreak): Hair Salon
- C-7: Waterbury, VT (Hurricane Irene, 2011): Restaurant
- C-8: St. Thomas, USVI (Hurricanes Irma and Maria, 2017): Brewery

C-1: Business Recovery in Long Beach Township, New Jersey (Hurricane Sandy)

Business Information

- **Business Name:** Living on the Veg
- **Business Type:** Restaurant
- **Structure:** Approximately 1,000 square feet
- **Employees:** About 15 in-season, 2 off-season
- **Damage:** 4.5 feet of inundation
- **Source of Information:** Owners

Key Findings

What sped up the critical path to recovery?

- Several non-profits and individuals with contracting experience led grassroots campaigns to educate businesses on the recovery effort. This effort provided businesses with a contractor as a point of contact and education about the entire process, education on mold remediation, coordinating volunteer help for demolition, painting, and other activities.
- Donations of money and supplies allowed some businesses to receive gift cards from hardware stores to perform demolition, mold remediation, and renovation activities.

What slowed down the critical path to recovery?

- The largest obstacle for this business and many other businesses was the lack of qualified and reliable electricians, plumbers, and contractors. There was an abundance of unskilled volunteers, but ultimately waiting for skilled labor slowed down the process by about 4.5 months. There were some issues with out-of-state contractors overcharging and/or performing substandard work, which built distrust about using out-of-area electricians and plumbers.
- Confusion about paperwork and insurance also played a role in slowing down this process. There was a lot of paperwork and time going into applying for grants and/or loans (e.g., SBA), and confusion about whether or not businesses with insurance were covered for flood losses. This long process and associated uncertainty about funding also slowed down the ability to get skilled labor for renovations.
- The recovery of the community played a large role in the resumption of normal business operations. Fewer visitors (and potential clients) slowed down operations in the summers of 2013 and 2014. Additionally, there were fewer employees available in the following two summers, which led to some shorter business hours.

What is being done to speed up the recovery process for potential future events?

- Businesses now have experience with the distinction between wind versus flood insurance coverage and some have purchased flood insurance.

- More water-resistant materials and practices were incorporated into renovations (e.g., raised electrical outlets, and cement board instead of gypsum board at lower elevations)
- Plans are in place to move most equipment to higher ground.
- Sandbagging of doorways, particularly during periods of nuisance flooding.

Recommendations for what else could be done to help with potential future events?

- Consider how the government or an NGO could provide help vet and direct electricians, plumbers, and carpenters, and other skilled contractors to areas with greatest need. There is a need for trusted and skilled labor.
- More outreach about the difference between wind and flood insurance—many businesses (and people) were not aware they were without insurance for flooding.
- Better dissemination of information on affordable, flood-resistant building materials and practices and best practices for mold control and remediation in cases where elevation is not an affordable option.

Critical Path to Recovery Details

Hurricane Sandy made landfall on October 29, 2012 and inundated the restaurant with 4.5 feet of water. We identified two key milestones for which the team assessed the critical path: the reopening of the restaurant about seven months after Sandy and the return to normal operations and revenue in the second season after Sandy (i.e., Summer 2014). The sections below provide further information on each of these critical paths.

Critical Path to Opening

Table 32 and Figure 16 present the critical path to reopening on June 1, 2013—approximately seven months after the disaster.

Critical Path to Normal Operations

The business owners reported that business was down in the summer of 2013 (summer following Hurricane Sandy), back to about 2012 levels in the summer of 2014, and finally above 2012 levels in the summer of 2015. The business is open all year, but "95%" of annual revenues are earned during the 10 weeks or so between the end of the school year in late-June and Labor Day.

There were fewer visitors to the island during the summer of 2013 as repairs on houses and motels were still ongoing, this generally reduced the number of clients.

Because of fewer visitors, there was a smaller pool of summer employees. This caused the business to have slightly reduced hours in 2013.

The critical path to normal operations was dependent on the rest of the community recovering and tourism returning back to normal and was an entirely different path than that identified in Table 32 related to the business opening.

Table 32. Critical path to business opening

#	Activity	Duration	Notes
1	Sandy Hits	Day 0	
2	Wait for access to island	Day 1 to Day 4 (4 days)	Access was not permitted except for emergency personnel.
3	Clean and bag up food mess	Day 5 to Day 6 (2 days)	Restaurant owners were allowed on the island for two days, primarily to bag rotting food and place it at the curb for collection and disposal.
4	Community meetings to develop community wide rebuild strategy	Day 7 to Day 9 (3 days)	There were a number of grassroots organizations that provided clarity for business owners about steps needed to move forward. Business owners were generally unsure of the process prior to this meeting as there were limited contractors available to help.
5	Demolition and mold remediation	Day 10 to Day 30 (about 3 weeks)	Business owners and homeowners were allowed back on the island starting on November 10. Business owners helped each other in very much a community effort. Grass roots organizations provided education on demolition and mold remediation. Much of the equipment was lost due to inundation in salt water.
6	Trying to secure renovation team	Mid-November, 2012 to late-March, 2013 (about 4.5 months)	A small number of businesses got up and running within two months if they did not have this wait period. The lack of supply of reliable and reasonably-priced electricians, plumbers, and contractors meant many businesses had to wait. The uncertainty about what funding would be available also played a role in slowing this down.
7	Renovation	April and May, 2013 (2 months)	Once this began, things moved quickly: permitting and inspections were done promptly.

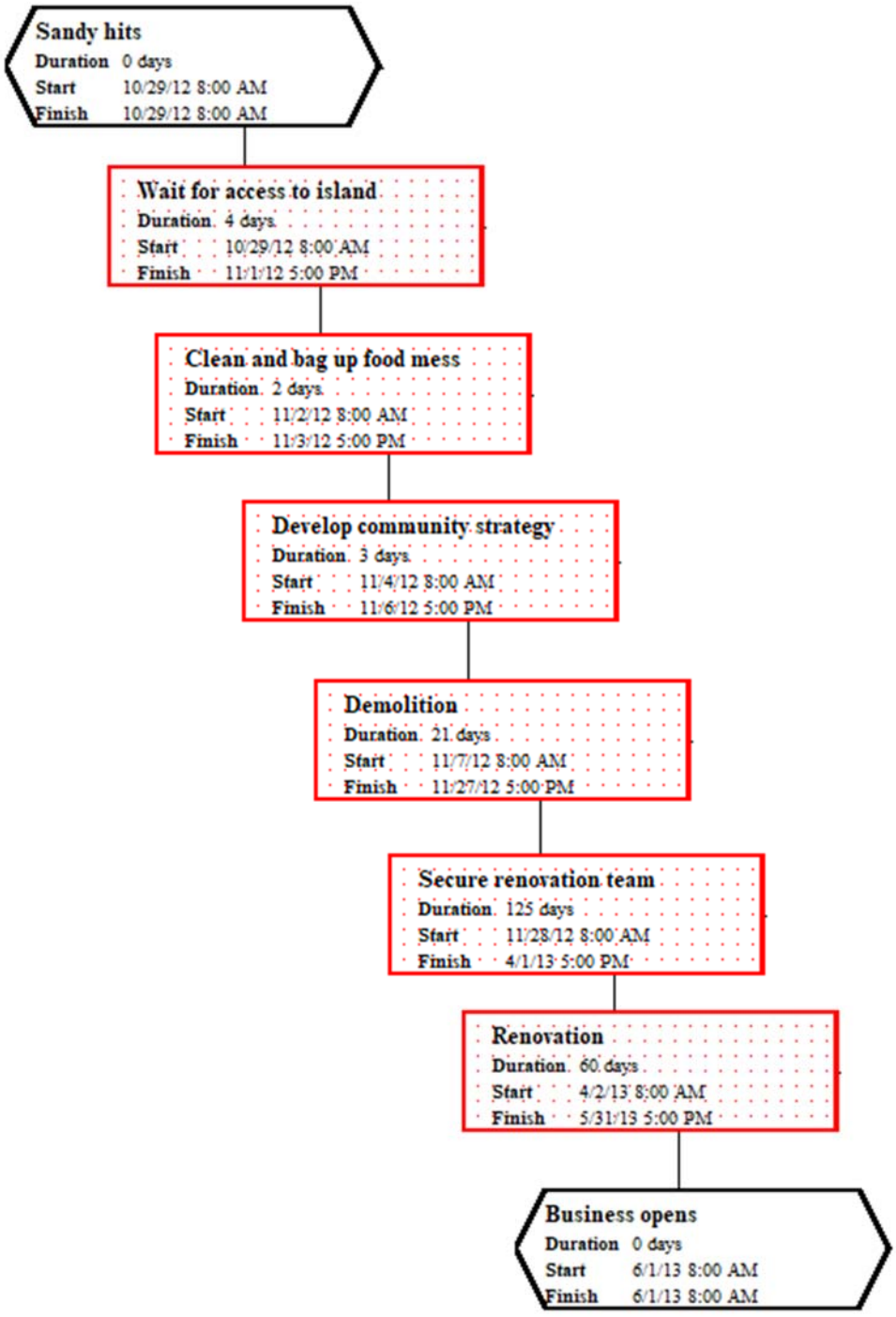


Figure 16. Critical path to business reopening

C-2: Business Recovery in Monroe County, Florida (Hurricane Irma)

Business Information

- **Business Type:** Hotel/Resort
- **Structure:** 14 Buildings and 44 rooms over 5 acres of waterfront property.
- **Employees:** 22
- **Damage:** Roof damage, and minor (a few inches) to major (a few feet) flooding of facilities.
- **Source of Information:** Owner

Key Findings

What sped up the critical path to recovery?

- Having in-house electricians, plumbers, and contractors. Other businesses were being charged unreasonable rates by out-of-state roofers (several times typical rate), and local workers were completely overloaded with repair jobs.
- AT&T brought mobile antennas on trucks to help with cell phone service and communication in the early days after the storm to improve communication.
- Owner did not wait to hear back from insurance companies or FEMA. They went ahead and made repairs without waiting for responses. They wanted to get back in business. Other businesses were unclear of what their policy stated, and insurance companies were backed up.
- While not a recommendation, a few staff stayed during the storm and were able to start assessing and clean up earlier. Given that, with communication down, nobody knew the status of the hotel for several days.
- Hotel provided housing to displaced workers and allowed them to stay alongside guests for a while. This kept them on as employees and allowed them to open earlier at partial capacity.
- In preparing for the storm, aluminum flood gates and sand bags placed at building entrances helped minimize damage marginally. Hotel also took their servers with them, which allowed them to keep their website updated following the storm. The hotel had sufficient propane on site to operate for a few weeks.

What slowed down the critical path to recovery?

- Though it seems like internet, phones (and less so, cable) would be critical to a hotel's opening (so guests can book rooms), the hotel reopened without these utilities. In their blog and in person, they mentioned that their service date was postponed several times by Comcast.
- Uncertainty about when water and electric service would return made the decision about when to open challenging. This led to a conservative estimate to give the hotel enough time to open.
- The housing shortage had less of an impact on the hotel than on other businesses, but there were very few places for recovery personnel to stay unless they brought their own RV.

- Some initial roofing repairs were not done correctly. Ultimately, the hotel used in-house labor to make fixes.
- Longer term, some external factors had impacts as tourists did not return to the island immediately. Nearby marinas were closed, and restaurants took several months to open. Debris in the streets and canals may have made the island an unattractive option for tourists for several months as well. Limited labor on the island primarily drove the critical path timeline for the rest of the island to recover.

What is being done to speed up the recovery process for potential future events?

- Hotel was expecting to renovate buildings over the next five years. They will be constructing a new building much higher (2 feet above code) to help avoid flood damage.

Critical Path to Recovery Details

Hurricane Irma made landfall on the Little Torch Key on Saturday, September 9, 2017 and continued through Sunday, September 10, 2017 (Day 0). The hotel, which is mostly below the flood level, took a direct hit from the storm. Twenty-nine of the hotel's forty-four rooms had roof damage and minor (a few inches) to major (a few feet) flooding. The hotel officially reopened at partial capacity, without access to some utilities and most of the amenities their guests usually enjoyed. Despite reopening relatively quickly, repairs are still ongoing. The hotel did not have internet, phone, or cable restored until approximately 15 days after reopening.

Critical Path to When Business Housed Displaced Residents

Table 33 and Figure 17 present the critical path to when the business could have been ready to open had they decided to do so. Instead they allowed displaced local residents to stay as well as several staff who lost their homes. The limiting factor for this ended up being electric service, which came back on approximately three weeks after Irma (about a week after water). Water restoration was needed for opening, but this was not on the critical path because water service was restored about one week before electric service. Additionally, assessments of the 15 rooms only took a few days and was not part of the critical path.

Table 33. Critical path to business housing displaced residents

#	Activity	Duration	Notes
1	Hurricane Irma hit	Day 0 (September 10)	Hurricane Irma hit Little Torch Key Saturday, September 9, 2017 through September 10, 2017 (Day 0).
2	Wait for restoration of electric service	About 3 weeks.	
3	Hotel could have reopened with 15 rooms	Day 21 October 1, 2017	Approximately 15 rooms (those undamaged by the hurricane) opened for non-commercial purposes.

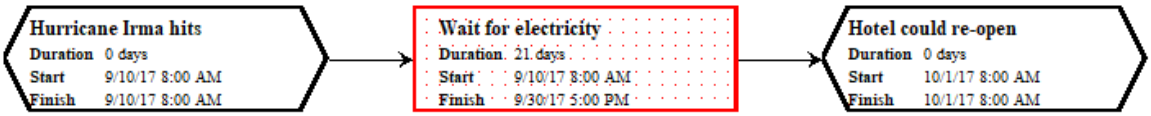


Figure 17. Critical path network diagram for the critical path to business housing displaced residents

Critical Path to Opening Commercially

Table 34 and Figure 18 present the critical path to reopening on October 15, 2017—approximately 1 month after the disaster. This critical path was based almost entirely on a conservative decision to cancel reservations for several weeks. This decision was made about a month before reopening.

In addition to the critical path activities there was one near-critical path activity identified:

1) **Electricity being restored:** This went on just before October 1.

Table 34. Critical path to business opening

#	Activity	Duration	Notes
1	Hurricane Irma hit	Day 0 (September 10)	Hurricane Irma hit Little Torch Key Saturday, September 9, 2017 through September 10, 2017 (Day 0).
2	Wait to learn about the status of the hotel	3 Days	US1 was not accessible for a few days nor open to residents, but aerial images of the hotel were available during this time.
3	Decision to cancel reservation for month and reopen.	32 days	Based on the aerial footage, the owners made a conservative decision to open on October 15. This was based on a mix of being in the off-season, understanding that staff might have their own issues to deal with, uncertainty with when water/electric would be on, and the nature of the business. Clients usually like to know a few weeks in advance, so they picked a conservative date and cancelled all reservations prior to October 15, 2017.
4	Hotel officially reopens	Day 35	Though the hotel reopened, it was operating at a limited capacity with their undamaged (15 of 44) rooms. Additionally, cable and internet were still not available.

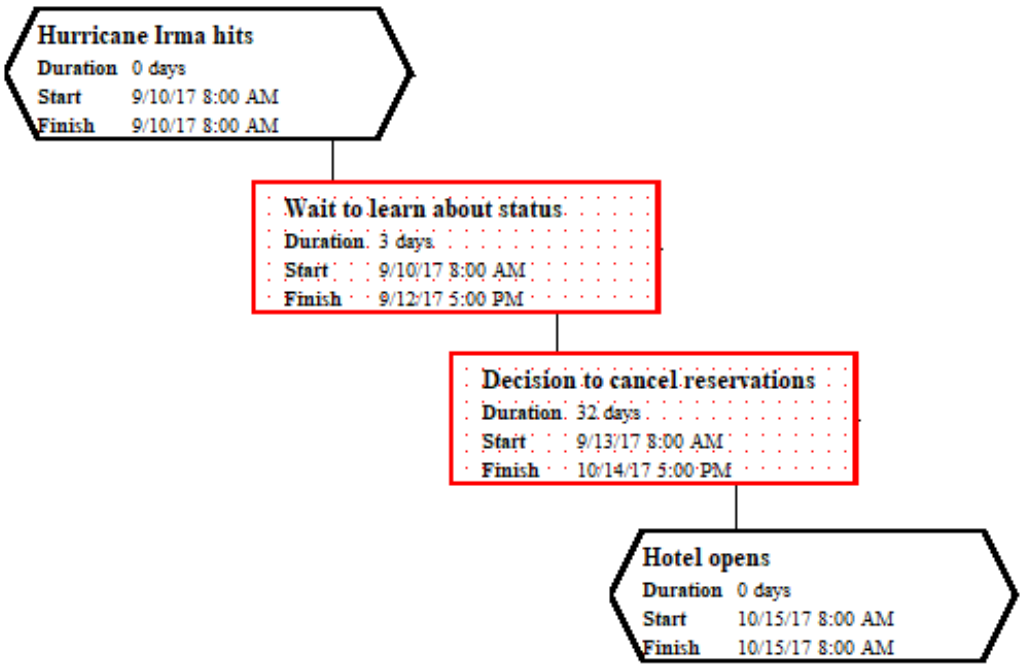


Figure 18. Critical path network diagram for reopening hotel

Critical Path to Opening Damaged Rooms

Table 35 and Figure 19 present the critical path to reopening many more rooms on December 15, 2017—just over three months after the hurricane. This critical path is largely driven by the time it took to repair the rooms, which was greatly facilitated by having an in-house plumber and electrician. This was also partially driven by the decision to assess each room and decide whether to tear down or keep the various buildings—ultimately, they decided to keep them in the short term and repair them instead of tear down and rebuild.

Table 35. Critical path to expanding capacity after fixing majority of damaged rooms

#	Activity	Duration	Notes
1	Hurricane Irma hit	Day 0 (September 10)	Hurricane Irma hit Little Torch Key Saturday, September 9, 2017 through September 10, 2017 (Day 0).
2	Wait for restoration of electric service	About 3 weeks.	
3	Situating those that were displaced	5 days	On 10/1, the hotel provided housing for displaced residents and employees. After this, the hotel was able to focus their efforts on what to do with the damaged rooms
4	Decision to keep or repair rooms	7 days	Owners decided to keep them in the short term and repair them instead of tear down and rebuild immediately.
5	Repair Damaged Rooms	About 2 months	This was primarily done with in-house contractors, plumbers, and electricians. Roofers were still not available at this point, so about seven
6	Hotel opens the vast majority of their rooms, including repairing many damaged rooms.	December 15, 2017	Hotel opened the vast majority of their rooms (all but 7 of their 44 rooms).

In addition to these above critical path activities there was one near-critical path activity identified:

1) **Cable/Internet restored:** This occurred around the beginning of November. This activity did not affect the timeline to repair the rooms, but some guests cancelled their reservations based on the availability of cable and internet during this period. It also did not impact the critical path from a perspective of opening the business, but this was a milestone as the hotel approached more normal operations.

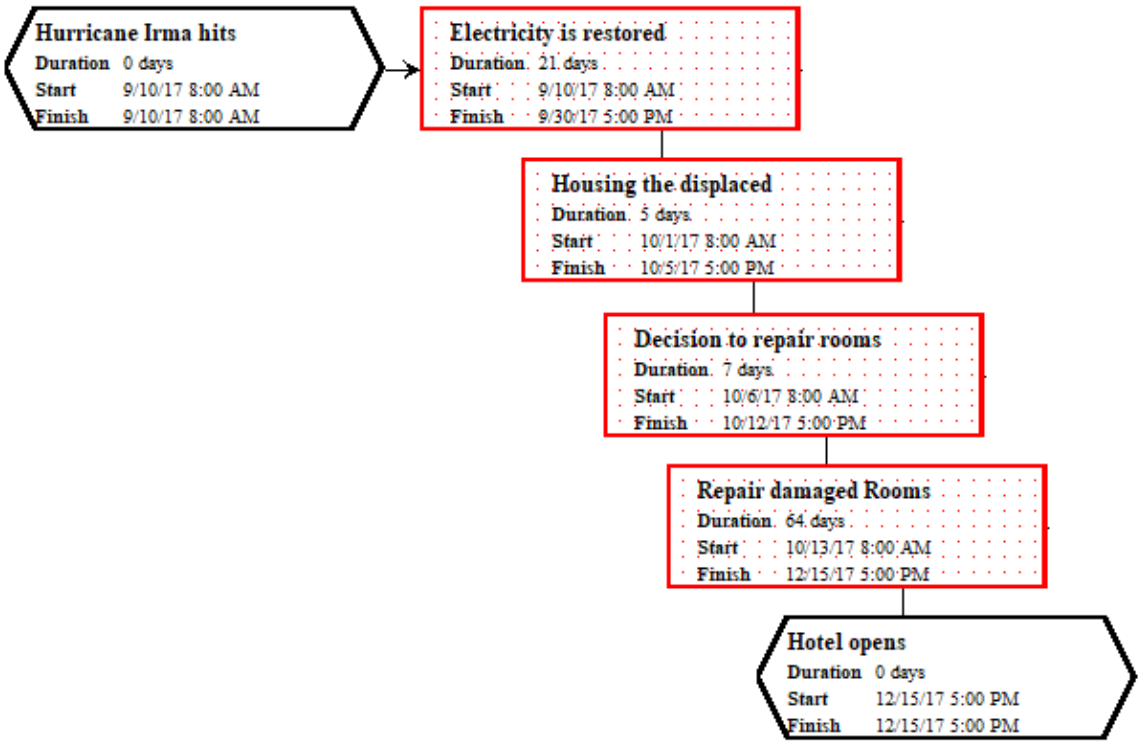


Figure 19. Critical path network diagram for expanding capacity after the fixing majority of damaged rooms

Critical Path to "Close to" Normal Operations

Most rooms opened—occupancy close to normal: Owner noted that by around March (six months after the event) operations were very close to normal—which they described as close to the typical occupancy rate. At this time, the hotel was still somewhat limited internally (some boat slips were still not repaired, the boat ramp was not fixed, and a couple of rooms were still not fixed); however, the critical path to occupancy may have been more driven by external factors such as the surrounding condition of the Keys. These factors, such as marinas shutting down, restaurants taking several months to open, and removing debris from the streets and canals, may have made the island an unattractive option for tourists for several months. Limited labor on the island primarily drove the timeline for the rest of the island to recover and seemed to be the driver of the critical path for more typical operations in terms of occupancy and overall experience of guests.

Very close to normal with some boating exceptions: Owner noted that by July 2018 (10 months after the event and time of the discussion) operations were normal with very few exceptions. They were at full capacity for mini-lobster season, had just fixed their boat ramp, and had 20/25 boat slips operating. The timing of the boat ramp repairs was primarily driven by wanting to be ready to go by mini-lobster season (a few days in late July). Notably, two local marinas were still shut down, which has impacted the ability of boats to get fuel, slightly impacting boating. Availability of more accessible marine fuel

may be an external driver to more normal boating operations, which is an important activity to many guests.

C-3: Business Recovery in Houston, Texas (Hurricane Harvey)

Business Information

- **Business Type:** Restaurant
- **Structure:** Large restaurant with capacity to serve around 600-900 people per night.
- **Damage:** Extensive damage from wind-driven rain entering through the roof and windows of the restaurant. Expecting to re-open in late February 2019, approximately 18 months after Harvey.
- **Source of Information:** CEO

Key Findings

What sped up the critical path to recovery?

- Business interruption insurance: This allowed employees to come in for three months and get paid, which enabled the employees to help with the initial clean up.

What slowed down the critical path to recovery?

- Issues with insurance: The insurance company severely underestimated the damage in the first assessment, which held activity up for two to three months. Owners also had difficulties documenting their claim.
- Funding: In the end, insurance did not come close to covering the cost of damage. The owners needed to put in substantial amounts of their own money and figure out other revenue streams to keep the process going. This held things up on several occasions.
- Landlord/tenant issues: There was some question about who is responsible for the damage since the landlord was responsible for the roof. These discussions slowed down some steps.
- Uncompleted work by contractors: A contractor performed much less work than promised for a large sum of money, which slowed down the repair process, led to funding issues, and slowed down the critical path.
- Additional damage: Completion of roof repairs after flooring repairs resulted in damage to the new flooring. This was related to the difficulty to coordinate between landlord and tenant.

What is being done to speed up the recovery process for potential future events?

- More robust insurance: Hire an independent claims adjuster to help reach a fair settlement with the insurer. Carry business interruption insurance and know what's covered (e.g., managers salaries could have been covered for 12 months if they had known)
- Plan sequence of repairs better (e.g., roof repair after floor repair resulted in damage to new flooring)
- Keep electronic records to support insurance claims and satisfy regulators, and make sure records are backed up offsite.

- Try to deal with potential mold sooner. This lengthened the cleanup process but ultimately did not slow down the critical path as waiting for insurance money for several months was on the critical path.

Critical Path to Recovery Details

Hurricane Harvey hit Houston, TX on August 25, 2017 and continued for several days, dropping about 50 inches or rainfall. The restaurant was not flooded by Harvey, but it sustained heavy damage to floors, walls, roofs, and kitchen equipment as wind-driven rain entered through a damaged roof and leaky windows. At the time of the interview, the restaurant was expected to open in about three weeks, so this represents the critical path to opening. At this time, we do not have information about whether it will open with normal revenue streams.

Critical Path to When Business Housed Displaced Residents

Table 36 presents the details of the critical path to recovery for when the restaurant is expected to open (tentative), and Figure 20 summarizes the steps graphically.

Table 36. Critical path to reopening restaurant

#	Activity	Duration	Notes
1	Harvey starts: August 25, 2017	Day 0	Hurricane Harvey hit Houston primarily as a heavy rain and flooding even. The restaurant was heavily damaged by wind-driven rain entered through the roof and windows.
2	Wait for storm to pass	2 days	
3	Assess property	2 days	
4	Submit initial information to insurance	12 days	Submitted information by mid-September 2017.
5	Wait for insurance results	September – mid-December 2017 (about 4 months)	This required a lot of back and forth and included the insurance company initially offering a very low settlement.
6	Empty out kitchen prior to kitchen floor repair	Late 2017 (two weeks)	
7	Kitchen floor repair	January-April 2018 (4 months)	
8	Roof repairs	May-June 2018 (2 months)	This step caused additional damage to the floor as the roofers damaged a grease catch, causing a new leak, and did not fix one section of roof correctly.
9	Kitchen Repairs (ovens, washers, additional damage from roof installation)	July 2018 to December 2018 (6 months)	This step was lengthened dramatically because a contractor did very little work and then did not return, slowing down the process as the owner searched for funding streams to complete the work the initial contractor had promised.
10	Health inspection	Early January 2019 (few days)	
11	Waiting for funding for final steps	January 2019 (one month)	The insurance settlement left a large gap, requiring the owners to consider a number of supplemental funding options throughout the process, which slowed down the path to recovery.
12	Purchase and setup kitchen arrangements, chairs, tables, and other settings	Late January to early February 2019 (few weeks)	
13	Purchase and install point-of-sale system	Early February 2019 (few days to set up)	
14	Employees back (about 2 weeks to hire and train): February, 2019	February 2019 (about 2 weeks)	
15	Tentative opening	Late February 2019	

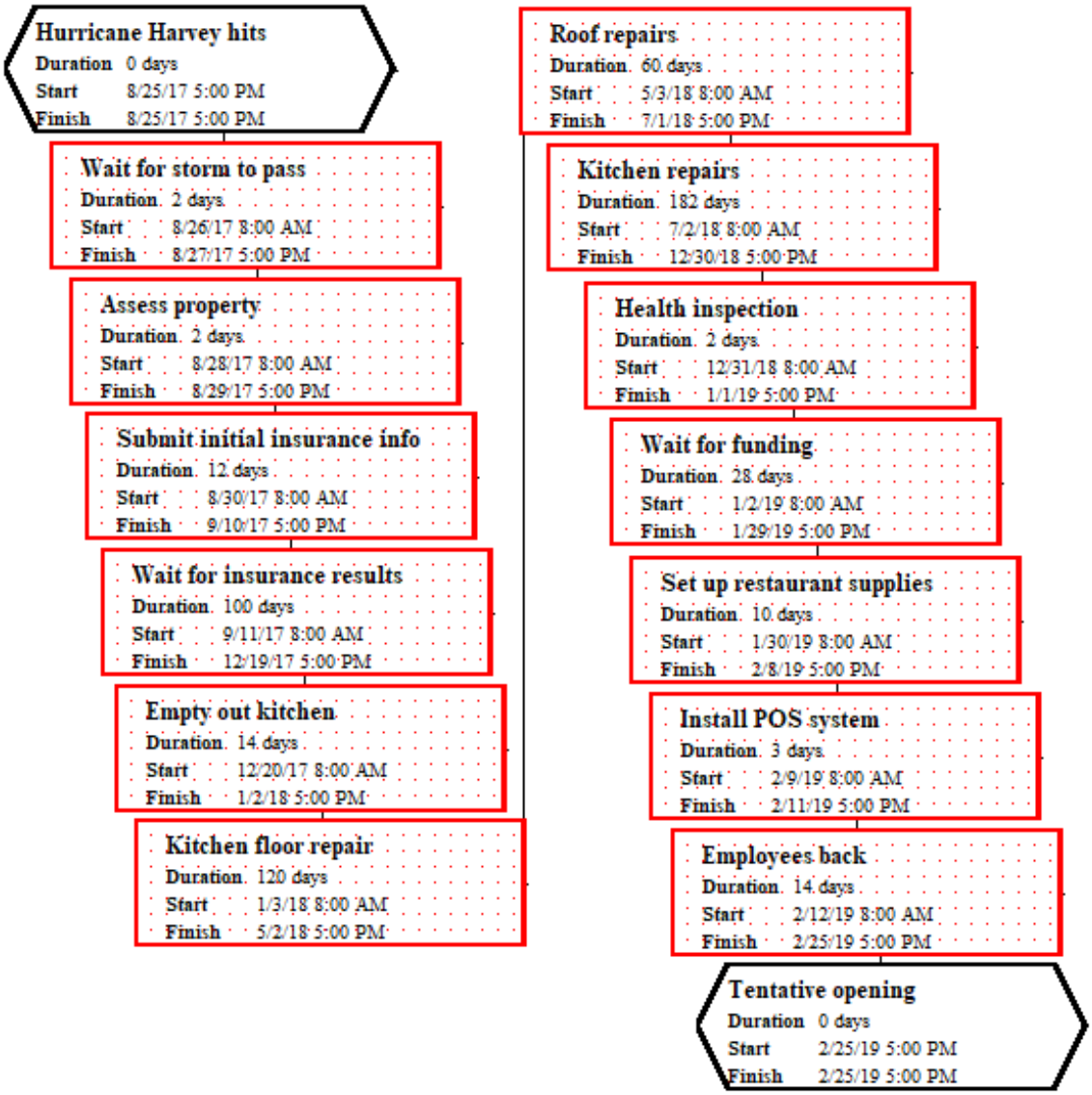


Figure 20. Critical path network diagram for reopening restaurant

C-4: Business Recovery in Port Aransas, Texas (Hurricane Harvey)

Business Information

- **Business Type:** Hotel
- **Size:** 23 hotel rooms and one office with living quarters
- **Damage:** Damage was most severe on the bay side of the property, where the storm surge inundation was highest. The buildings sustained damage from flooding and wind. Nineteen units were green tagged (light damage primarily to subfloors; two units were red tagged (heavy damage); and two units plus the office were yellow tagged (moderate damage) by the state.
- **Information Source:** Owner

Key Findings

One recovery milestone includes opening the hotel to displaced residents, which occurred on Day 13. The other recovery milestone included opening to the public on March 8, 2018, just over 6 months after the hurricane.

What sped up the critical path to recovery?

A local resident opened up "Cowboy Camp David," which provided meals for many recovery workers. This allowed more time for recovery activities and less time worrying about food for everyone involved.

- The hotel had a reserve of several months of operating revenue, which allowed them to pay contractors immediately.
- The hotel had two generators on site, which helped with drying activities to prevent mold.
- The hotel lined up contractors while evacuating, so they were one of the first businesses to recover.

What slowed down the critical path to recovery?

- The hotel could have used about 4 to 5 more generators than they had (2).
- The fiberglass insulation below the subfloors trapped moisture against the subfloors and caused extensive damage.
- The vinyl flooring also trapped moisture, so it all needed to be removed.
- The first contractor did not have the help to finish on target (spring break 2018), so they needed to hire a second contractor.
- It took over two months to receive the insurance settlement for the roof. This did not slow down the critical path, but if could have if the roof repairs were lengthened much further.
- It took over one month to receive the flood insurance settlement. This did not slow down the critical path, but it could have if the owners did not have extra money on hand to pay contractors.

Recommendations for what else could be done to help with potential future events?

- The hotel is now using spray-on closed-cell insulation below the subfloors to reduce the risk of trapping moisture in a future flood event.
- Using tile and grout that can better withstand floods in future (compared to vinyl which cannot).

Critical Path to Recovery Details

Hurricane Harvey impacted the hotel with Category 4 winds and flooding from a bayside storm surge. The surge inundated at least the subfloor of all 23 rooms, which meant they needed to gut and replace subfloor for every room. Of note, phone and internet were restored by Day 24 and potable drinking water was restored by Day 13, but neither of these was on the critical path. Additionally, it took about 60 days to find permanent housing for displaced local residents who were staying at the hotel. This also did not impact the critical path to recovery. The critical path to the hotel opening all 23 rooms is presented in Table 37 and Figure 21.

Table 37. Critical path to hotel opening all 23 rooms

#	Activity	Timing / Duration	Notes
1	Hurricane Harvey hit	Day 0 (August 25)	Hurricane Harvey hit Port Aransas, TX August 25, 2017.
2	Wait to access island	3 days August 28	Residents were not allowed back on the island and nobody could safely make an assessment.
3	Preliminary damage assessment	Day 3-4 August 28-29 2 days	A few bayside units were heavily damaged as flooding came from bay. The office was inundated with a couple feet of water. Subfloor was damaged in most units.
4	Clear out, dry out, and bleach rooms	Day 5 - Day 8 August 30 - Sep. 2 (4 days)	Remove all wet debris from rooms. Obtain fans and generators to start drying rooms. Bleach rooms.
5	Repair rooms	Day 9 - 190 6 months Sep. 3 - Mar 3	The hotel instructed contractors to do this on a rolling basis as many of the rooms were livable before being fixed up and this would allow guests to stay in the new rooms once repaired. This was slightly slowed down by the very lengthy process to get flood insurance settlement (over a month) and wind insurance settlement for the roof (2 months); however, the owners used much of their money up front to pay contractors to overcome this delay. Roof repairs were done with guests on site and did not play into the critical path. All 23 rooms done by day 189; 10 rooms done by day 119; and 2 rooms done by day 35.
6	Setup and decorate each room	Day 191-194 March 4-7 4 days	The hotel repaired all 23 rooms on a rolling basis. Each one took about 4 days to decorate with pictures, setup beds, and setup all other equipment after contractors were done.
7	Inspect final room	Day 195 March 8, 2018 <1 day	The hotel repaired and had inspected all 23 rooms on a rolling basis. Each one took less than a day to inspect.
8	Hotel opens all 23 rooms to public	Day 195 March 8, 2018	

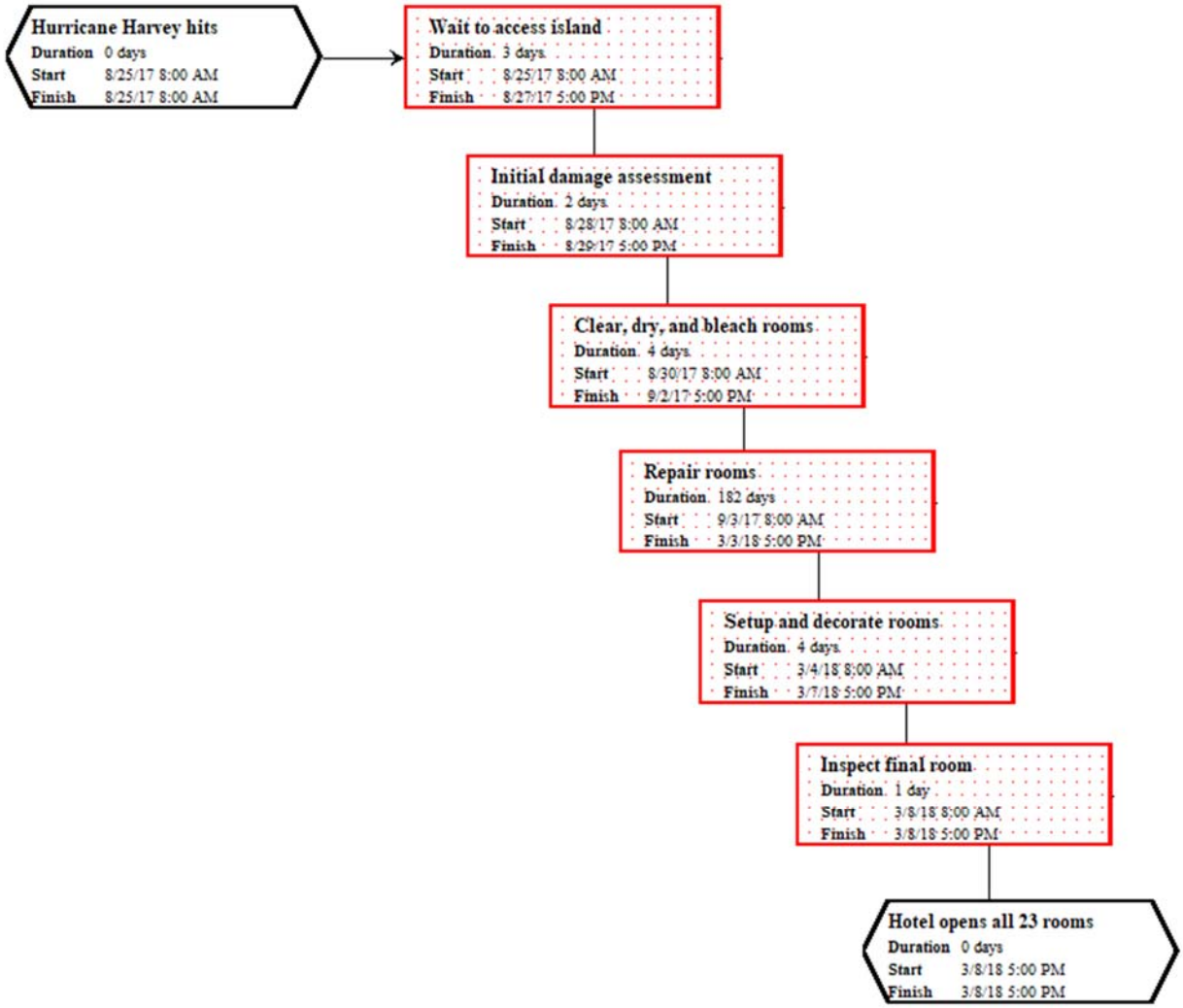


Figure 21. Critical path network diagram for opening all 23 rooms

Before undergoing construction, the hotel took in displaced local residents. This was driven by waiting for Port Aransas to restore potable water, which took about 13 days. The critical path is detailed in Table 38 and depicted in Figure 22.

Table 38. Critical path to taking in displaced residents as guests

#	Activity	Timing / Duration	Notes
1	Hurricane Harvey hit	Day 0 (August 25)	Hurricane Harvey hit Port Aransas, TX August 25, 2017.
2	Restore potable water	13 days	This was the major driver for allowing displaced local residents to stay.
3	Take in first displaced residents as guests	Day 14 September 8, 2017 (15 days)	19 of the 23 rooms were green tagged and usable so many of these were used for displaced residents to rent inexpensively.

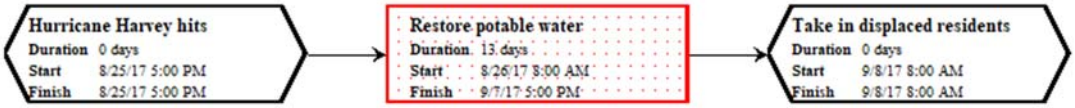


Figure 22. Critical path network diagram for taking in displaced residents as guests

One final milestone included the hotel opening to the general public at Day 60. This was driven by waiting for displaced residents to find permanent housing.

In terms of finding long-term normal operations, it is still too early to tell. There are fewer visitors to the island, but there are also fewer options for guests to stay because not everyone recovered. The hotel experienced one of its best spring breaks ever shortly after opening because they were one of the few to open early.

C-5: Business Recovery Case 1 in Tuscaloosa, Alabama (2011 Tornado)

Business Information

- **Business Type:** Quick service restaurant
- **Structure:** Structure was built in the 1980's. Post-tornado size is substantially larger, approximately 5,000 sq. ft.
- **Employees:** Pre-tornado: 28; Post-tornado: 41. During the reconstruction phase, restaurant maintained about three employees to "run routes," delivering their products (from another family-owned shop) to Tuscaloosa grocery stores to maintain a presence in the community.
- **Damage:** Building was completely destroyed. The only room left intact was a bathroom adjoining the back office, where the five employees working on the day of the tornado fortunately decided to take shelter.
- **Source of Information:** Owner/Franchisee.

Key Findings

What sped up the critical path to recovery?

- Insurance quickly made payment to business.
- Owner's friend was a contractor who had equipment to clear debris quickly.
- Hiring outside firm to dispute flood map changes proposed following the event, allowing them to avoid restrictions on the size and location of the new building.

What slowed down the critical path to recovery?

- Debris in the roads delayed access to the building immediately following the event, which in turn delayed damage assessment.
- Back-and-forth with city over egress roads through the property for new adjoining development.
- The City of Tuscaloosa issued a 90-day building moratorium on new construction within the recovery zone.
- Updates to flood maps.
- Back-and-forth with corporate design team.

What is being done to speed up the recovery process for potential future events?

- Better understanding of insurance coverage.

Lessons Learned:

- It is important to understand insurance policy, what is covered, what can be changed.

Critical Path to Recovery Details

The owner had about 45-minutes to one-hour of lead time to notify employee working in store of the impending tornado because it had just hit part of his family farm. Employees sheltered in place in a bathroom adjoining the back office, which was the only remaining

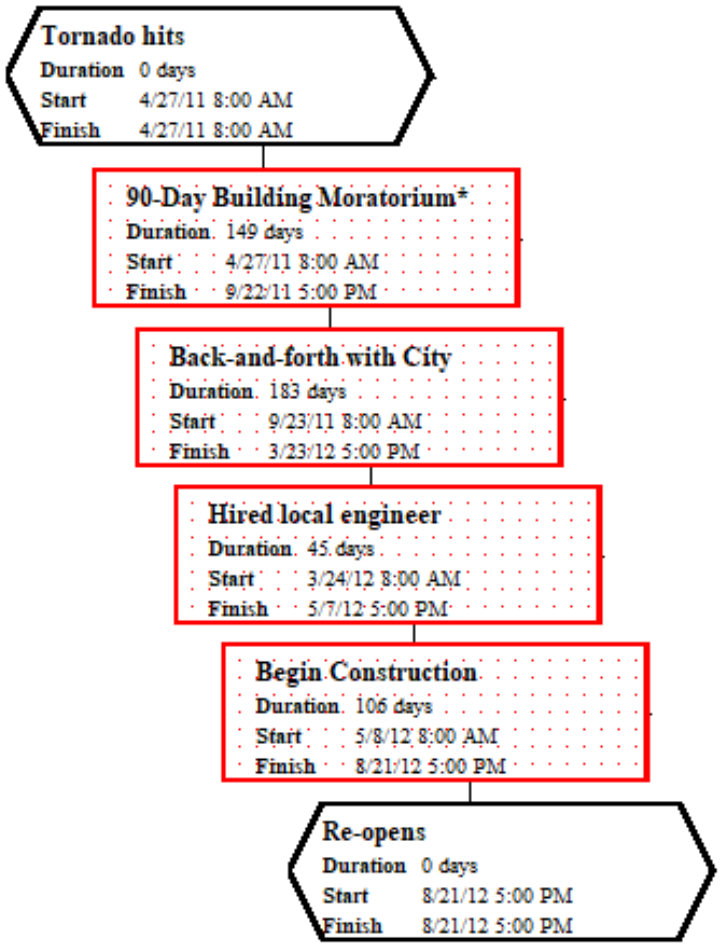
and undamaged room after the tornado hit. The owner's friend, a contractor, was able to clear debris from his property within 48 hours. The City's building moratorium, the Tuscaloosa Forward plan (cause of egress road dispute), and the flood map updates slowed the restaurant's critical path to recovery. The owner indicated that he felt without these delays, they could have reopened 5-6 months earlier than the actual date of August 21, 2012. The owner engaged an outside consulting firm to perform an independent study that ultimately placed the restaurant and several other businesses outside of the new flood zone, saving time and money.

Critical Path to Reopening

Table 39 and Figure 23 present the critical path to reopening.

Table 39. Critical Path to reopening

#	Activity	Duration	Notes
1	April 27, 2011 – Tornado hits and destroys building	Day 0	The five employees on duty sheltered in a bathroom adjoining the back office. It was the only portion of the building still standing after the event.
2	City Issues 90-day Building Moratorium on May 10, 2011	Started Day 13 (90 days; May 10 to ~Aug. 10)	No new building permits were issued during this time. This time was used to assess damages and write the Tuscaloosa Forward redevelopment plan.
3	Back-and-forth with City over egress roads, entrance/ exits, and location of business on lot	Late September 2011 – March/April 2012 (~5-6 months)	As part of the Tuscaloosa Forward plan, new rules about business location (as close to street as possible) and relocated egress roads for new development were major slowdowns for rebuilding. One aspect of this slowdown was the widening of McFarland Boulevard. Additionally, the city wanted to put a road right behind the restaurant for egress out of a new retail area, which impacted their drive through. The owner estimated that this process delayed his reopening approximately 5-6 months.
4	Hired local engineer to submit design package	March/April 2012 (45 days)	The owner hired a local engineer to prepare and submit construction package which was a very quick process
5	Begin Construction	April 20, 2012 – Early August (~3.5 months)	After back-and-forth with the city was sorted out, construction was a very fast and smooth process.
6	Restaurant reopens	August 21, 2012 (~16 months after the tornado)	Restaurant reopens on August 21, 2012 and had so many customers police had to direct traffic. Restaurant retained all core employees and had better weekly revenue following the reopening than ever before.



* The 90-day moratorium includes some wait time before and after (the actual moratorium started May 10)

Figure 23. Critical path network diagram for reopening

Near-Critical Path Activities

The building moratorium lasted 90 days and ultimately drove the critical path early in the process. These were some of the first steps that took place that would have been part of the critical path in the absence of the moratorium.

- It took the owner about 12 hours to get to the business following the tornado due to impassable roads and debris.
- The damage assessment and salvage took less than a day.
- The owner contacted all employees and determined that none had incurred major damages to their homes. The owner had business interruption insurance covering employee salaries for 1 year.
- In days 2 and 3, one of the owner's contractor friends cleared debris in 48 hours.
- Within the 90-day moratorium, the owner received insurance payment for the building for the full value of the policy. The owner decided to take out a private loan in addition to the insurance payment to build back "bigger and better."

- After the moratorium, a new flood map was proposed for the area, which initially put the business inside the 100-year floodplain. The owner engaged an independent consultant to dispute the proposed map. This process took less time than the back and forth with the city about determining whether a point of egress from the strip mall would need to go through their drive through, so it was not on the critical path. However, it was a distraction that may have slowed down the owner's negotiations with the city and the developers of the adjoining property about the egress issue.

C-6: Business Recovery Case 2 in Tuscaloosa, Alabama (2011 Tornado)

Business Information

- **Business Name:** Boulevard Salon
- **Business Type:** Hair salon
- **Structure:** 1,344 square foot standalone structure. The property was constructed in the 1960's as a house (part of residential neighborhood) and prior to the tornado had been remodeled several times into a salon (2010). The new structure is 1,484 square feet.
- **Employees:** None. The owner rents "salon rooms" to independent contractors who pay rent. Pre-tornado, there were 6 renters. Currently there are 7 renters.
- **Damage:** Extensive damages resulting in complete teardown. Tornado was about 1-mile wide and touched ground for approximately 5.9 miles. Boulevard Salon was directly in the Tornado's path.
- **Source of Information:** Owner

Key Findings

What sped up the critical path to recovery?

- The owner's father is a licensed contractor who had all the equipment and materials necessary to start clearing debris immediately. He also had a thorough knowledge of building codes and the permitting process, enabling him to work quickly and efficiently after a building permit was issued.
- They had cash flow available to start rebuilding without needing to wait for insurance.
- Insurance made adequate payments immediately to keep the building process going.

What slowed down the critical path to recovery?

- On May 10, 2011 the Mayor of Tuscaloosa issued a 90-day building moratorium on new construction within the recovery zone. This was the beginning of the development of Tuscaloosa Forward, a City-wide redevelopment plan that slowed down the rebuilding process of many small businesses.
- Updates to flood maps following the tornado put part of the salon and several other businesses in the 100-year flood zone. This required the salon to change the placement of an air conditioning unit.
- The owner identified the following as hurdles impacting other businesses that did not reopen as quickly:
  - Getting SBA loans or other government loans
  - Flood map updates put some businesses in the floodplain
  - Cash flow issues
  - Moratorium devalued property, which made getting financing more difficult.

What is being done to speed up the recovery process for potential future events?

- The owner has learned more about property rights, current municipal building codes, and insurance coverage to navigate these issues for a quicker recovery.
- Coordinate with local government about emergency plans beforehand.

Critical Path to Recovery Details

The Tuscaloosa Tornado touched ground in Tuscaloosa, Alabama just after 5:00pm on April 27, 2011. The tornado was approximately 1-mile wide and traveled approximately 5.9 miles through Tuscaloosa. Boulevard Salon was in the middle of the tornado's path and was completely destroyed, along with thousands of other homes and businesses. The salon was completely rebuilt and reopened on March 1, 2012. Shortly after reopening, the salon reached pre-tornado staffing (independent contractors leasing salon space). The owner rented space at an unaffected salon a few miles away and worked out of that salon starting seven days after the tornado to maintain her clientele.

Critical Path to Reopening

Table 40 and Figure 24 present the critical path to recovery to Boulevard Salon reopening about 10 months after the tornado. Two months after reopening the building, the owner had fully leased out her studios. Independent stylists lease out each studio and have their own clients. At 10 months, the salon reopened with 4 of the 7 studios rented. It took about two months to lease the remaining three studios (12 months after the tornado), which represented a return to normal operations.

Table 40. Critical path to opening salon

#	Activity	Duration	Notes
1	Tornado touches down April 27, 2011	Day 0	Tornado hit touched down just after 5:00pm.
2	90-day building moratorium May 10, 2011	Day 13 (90 days; May 10 to ~Aug. 10)	No new building permits were issued during this time. This time was used to assess damages and write the Tuscaloosa Forward redevelopment plan.
3	Prepared permit package	~August 10 – September 29 (50 days)	The owner's father was very familiar with this process. He hired a draftsman (business was not large enough to require an architect).
4	Apply for building permit	September 30, 2011	
5	Iterate on issues	September 30 – October 20 (20 days)	Boulevard had to relocate AC unit outside of the new flood zone, adhere to Tuscaloosa Forward's 10% of parcel green space rule, and new property access rules that caused problems for many nearby businesses.
6	Building permit issued	October 20, 2011	
7	Construct salon	October 20 – Late February (~4 months)	No significant delays, shortages of labor or materials. There were minor inspection issues, but the owner's father cleared them up very quickly, as they were not out of the ordinary.
8	Certificate of occupancy	Late February 2012	
9	Salon reopened March 1, 2012	March 1, 2012	Salon reopened with 4/7 studios filled. The studios are rented by independent contractors who have their own clients.
10	Salon is fully staffed/ leased	May 1, 2012	All 7 studios leased. This represented a return to normal operations.

Near Critical Path Activities

The building moratorium lasted 90 days, driving the critical path to the recovery early in the project. Had the moratorium not occurred, these items would have contributed to the critical path.

- Assess damage (about 1 day): The owner lived close to the salon. Her husband was able to walk to the salon and perform damage assessment fairly quickly. Had she lived further away, traveling to the salon would have been more challenging because the roads were impassable.
- Clear debris (about 9 days): The owner's father (licensed contractor) cleared debris and salvaged contents using his own machinery/equipment after being required to obtain a demolition permit (~May 4th).
- Receive insurance payments (within 90-day moratorium): Owner had good insurance and payments were made very quickly.

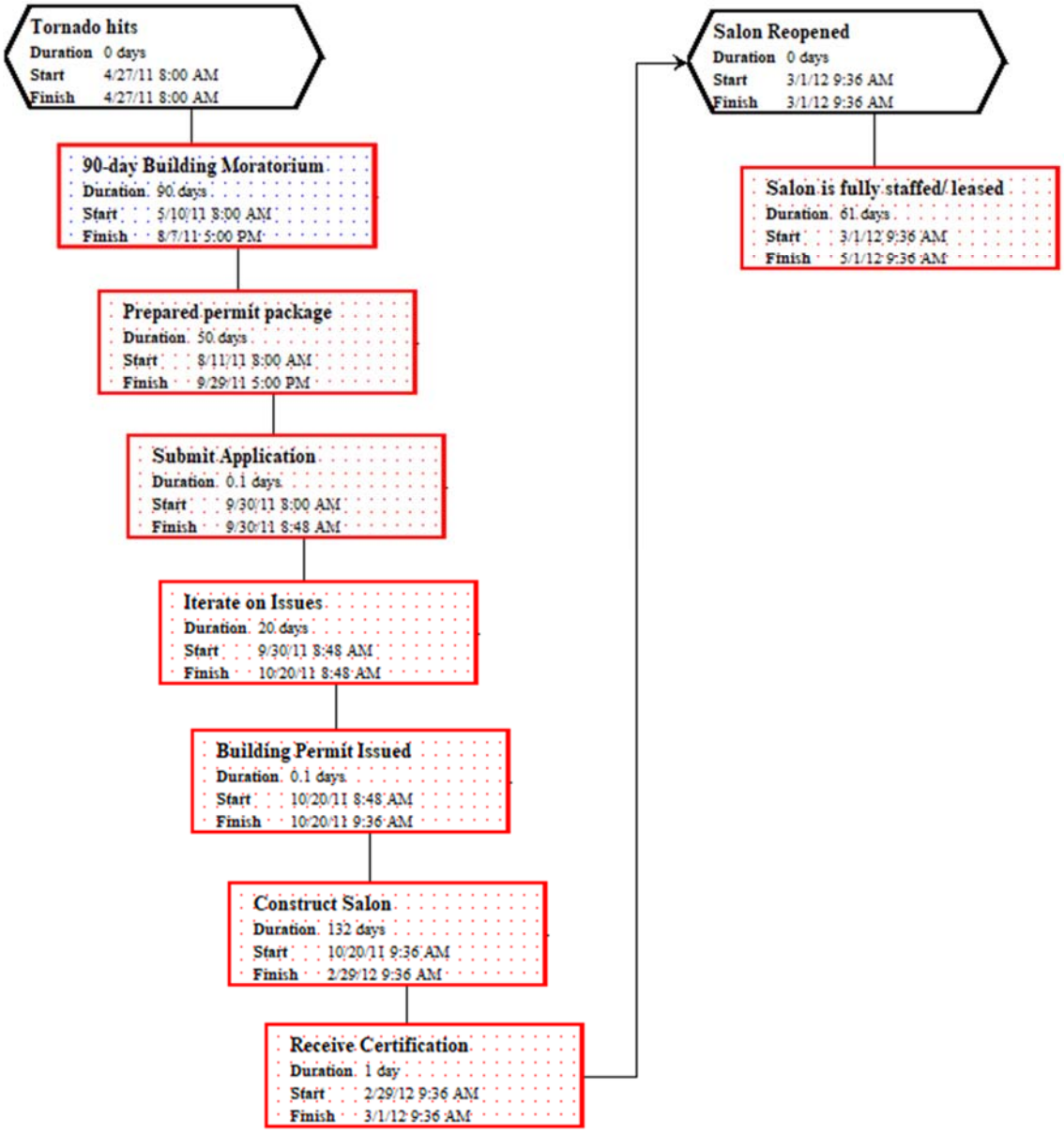


Figure 24. Critical path network diagram for reopening the salon

C-7: Business Recovery in Waterbury, Vermont (Hurricane Irene)

Business Information

- **Business Type:** Restaurant
- **Structure:** The first floor is about 4,000 square feet. The owner of the building had several tenant businesses (restaurant, hair salon, paper scrap store) and also owned the restaurant.
- **Employees:** This was the same before and after the storm.
- **Damage:** The first floor was flooded with about five feet of water. The restaurant is primarily on the second floor (kitchen and serving area), but the food storage room was on the first and the inventory/ supplies in that room were destroyed. The other first floor tenants (hair salon and paper scrap store) were badly damaged (sheet rock, floors, amenities, and equipment all needed to be replaced). The water rose relatively slowly, as opposed to a more destructive, high velocity flow.
- **Source of Information:** Owner

Key Findings

What sped up the critical path to recovery?

- For the restaurant to open up:
  - The kitchen and serving area were sited on the second floor, above the flood damage.
  - Pre-existing relationships with electricians and contractors allowed the repairs to be done immediately after the storm.
  - Volunteers helped with clearing out and cleaning up the storage room of the restaurant.
  - The town made dumpsters widely available, which made the clean-up process easier.
- To repair the rest of the building for other tenants:
  - Money available quickly: Being able to get a loan within seven days from a state business lending organization (Vermont Economic Development Authority [VEDA]) as well as a line of credit. Other grants came from the HUD CDBG-Disaster Recovery program, but these were long after the costs were incurred.

What slowed down the critical path to recovery?

- For other businesses, SBA loans were a cumbersome process, but the owner decided to not pursue this funding option.

What is being done to speed up the recovery process for potential future events?

- Boiler was relocated to the second floor, away from potential flood-prone area.
- Electrical panels and circuit breakers were moved to the second floor, away from potential flood-prone area.

Critical Path to Recovery Details

Hurricane Irene was primarily a rain event by the time it made it to Northern Vermont on Sunday, August 28, 2011. Saturated grounds from a wet summer caused more water to run into the river, flooding portions of the town. Below, we present the critical path of a restaurant reopening and discuss the driving factor for normal operations.

Critical Path to Reopening Restaurant

Table 41 and Table 42 show two parallel critical paths to the restaurant's opening five days after Irene hit. If either activity—cleaning out the storage room or electrical work—had taken another day, it would have delayed the opening of the restaurant. Thus, we present two critical paths to recovery below. Of note, the restaurant opened in about five days but without heat. It would have taken a little over a month to open had it not been the end of the summer as they waited for a new boiler to be put in. The two paths are depicted in Figure 25.

Table 41. Critical path to restaurant opening

#	Activity	Duration	Notes
1	Irene hits on Sunday, August 28, 2011	Day 0	Heavy rain caused the river to rise several feet above the 100-year flood plain. There was about 5 feet of water on the first floor of the restaurant (storage area only). The kitchen and serving area were on the second floor.
2	Clear out storage area	Day 1-2 (2 days)	The storage area (food primarily) was the only part of the restaurant on the first floor. This was sped up by volunteers and employees helping to clear out area.
3	Clean up storage	Day 3-5 (done early Friday) (2 days)	This included cleaning and drying out the area before it could be restocked. This was sped up by employees and volunteers helping to clean up the area.
4	Restock food	Day 5 (a few hours)	The restaurant ordered food the night before when it was clear the storage area would be cleaned up for Friday. Food came in on Friday morning so the restaurant could reopen later that day.
5	Restaurant reopened	Day 5 (Friday night)	The restaurant opened fully staffed but without heat. Heat was not critical because of time of year (early September). It took another month before the boiler was repaired.

Table 42. Parallel critical path to restaurant opening

#	Activity	Duration	Notes
1	Irene hits on Sunday, August 28, 2011	Day 0	Heavy rain caused the river to rise several feet above the 100-year flood plain. There was about 5 feet of water on the first floor of the restaurant (storage area only). The kitchen and serving area were on the second floor.
2	Electricians fixed and moved panels and circuit breakers	Days 1-3 (3 days)	The restaurant owner had pre-existing relationships with electricians which helped secure this scarce resource.
3	Inspectors sign off on electrical work.	Day 4 (hours)	There were a limited number of inspectors, so the restaurant was fortunate this happened quickly once work was done.
4	Power company turns on power	Day 4 (later in day)	Once the state inspectors signed off on the electrical work, the power company turned on the power a few hours later.
5	Restaurant reopened	Day 5 (Friday night)	The restaurant opened fully staffed but without heat. Heat was not critical because of time of year (early September). It took another month before the boiler was repaired.

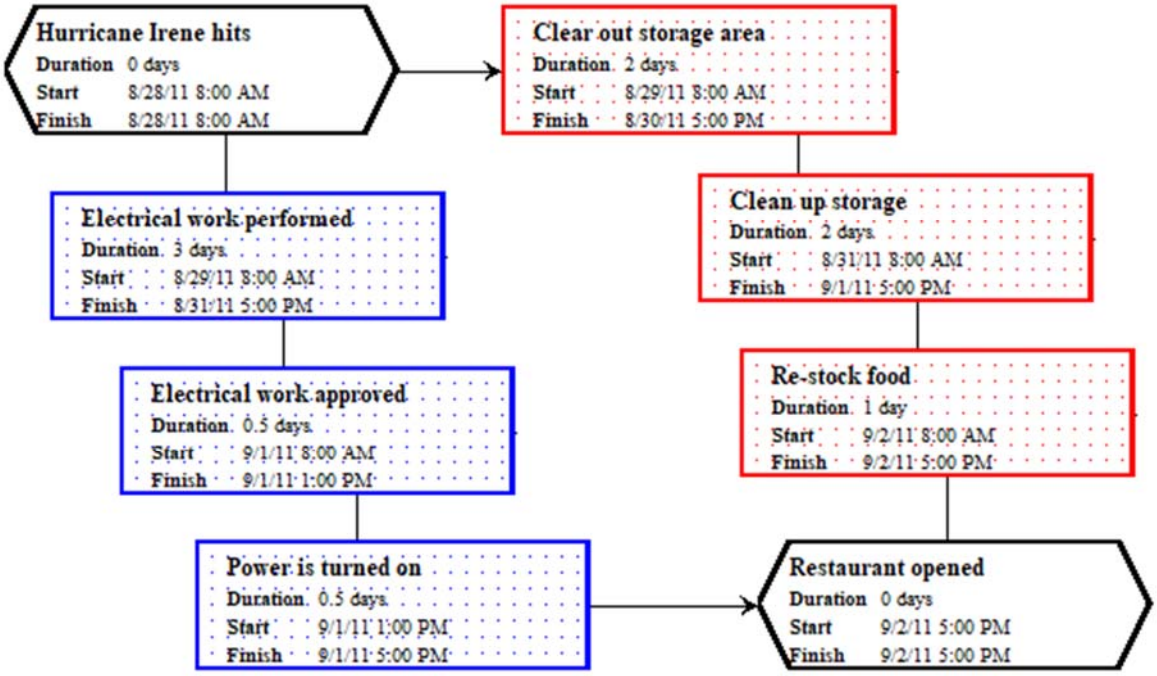


Figure 25. Critical path network diagram for reopening the restaurant

Critical Path to Pre-Event Revenue for the Restaurant

After reopening, the restaurant had increased revenue compared to pre-storm levels for about four to five months because of all the workers helping to rebuild the community. Beyond that point, a few new restaurants opened, and the restaurant operated at about 80 percent of the revenue it took in prior to Irene due to the increased competition and the fact about 1,500 state workers and many more workers from Green Mountain Coffee had moved out of Waterbury following the storm. In November 2015 (51 months later), the state workers moved back to their location in Waterbury. That combined with some re-

branding by the restaurant and some craft beer breweries opening up seemed to coincide with the restaurant reaching pre-event revenue. The craft beer breweries helped draw in more tourists.

Critical Path to Repairing the Rest of the Building

The owner of the restaurant owned the whole building complex, which included five other tenants. All of the retail space in the building took about two months to repair. The owner was less certain about the sequence and length of steps as it was about eight years ago. Generally, this involved removing equipment, fixing floors, removing sheetrock and otherwise gutting the first floor then bringing in a contractor to oversee the rebuild.

C-8: Business Recovery in St. Thomas, US Virgin Islands (Hurricanes Irma and Maria)

Business Information

- **Business Type:** Microbrewery
- **Structure:** Brewery is approximately 500 square feet with direct access outside so customers can be served in the brewery.
- **Damage:** Damages to the brewery portion of the building were extremely minimal. The brewery remained dry through both hurricanes. The only damage was to an aluminum exterior stack vent, used to vent heat and odor out of the brewery. This was caused by the wind.
- **Source of Information:** Owner

Key Findings

What sped up the critical path to recovery?

- The owners were very well prepared for the hurricane, as they regularly prepare for hurricane season by preparing excess supplies (batteries, meals ready-to-eat (MRE), water, etc.). Additionally, the owners kept excess brewing ingredients on shelves in the garage of their home.
- Brewery was in sound financial condition prior to the hurricanes, which reduced the need for FEMA Assistance and SBA loans prior to reopening the business. The owner started to apply for assistance, but the process was very complicated and the loans were not essential.

What slowed down the critical path to recovery?

- The brewery had beer in the tanks at the time of the hurricane which had to sit for almost three months until electric service was restored. Therefore, a thorough cleaning of the tanks was required following the restoration of electricity.
- Brewery did not have its own generator and thus had to wait to start cleaning the brewing tanks until electricity was restored to the building.

What is being done to speed up the recovery process for potential future events?

- The owners replaced all windows with impact resistant windows to mitigate risk of future damages. This decision was in response to minor water damage around a single window in the office portion of their space.

Critical Path to Recovery Details

Hurricane Irma, a category 5 hurricane, passed just to the north of St. Thomas on September 6, 2017 with sustained winds of over 180 mph. Following Hurricane Irma, Puerto Rico and St. Croix sent substantial aid to St. Thomas and St. John. However, two weeks after Irma, Hurricane Maria (September 20, 2017), a category 4/5 hurricane, hit the USVI, passing almost directly over St. Croix, before moving directly over Puerto Rico, cutting off aid to St. Thomas and St. John. Though St. Thomas and St. John did not

sustain as direct of a hit from Hurricane Maria as they did from Irma, Maria's winds exacerbated damages to the already impacted islands. Much of the recovery progress that had been made on St. Thomas and St. John following Irma had to be redone after Maria. The owners sheltered in their basement during Irma only to discover that their garage was the only remaining part of their house. They lived in their office for about eight weeks following Hurricane Irma.

Critical Path to Recovery

Table 43 and Figure 26 present the critical path for brewery reopening.

Table 43. Critical path to brewery reopening

#	Activity	Duration	Notes
1	Hurricane Irma hits September 6, 2017	Day 0	Hurricane Irma was a category 5 storm that passed over the northern parts of St. John and St. Thomas. Hurricane Maria struck on September 20, 2017.
2	Restore electricity	Day 83 November 27, 2017	Electricity was restored 83 days after Irma hit. This was relatively quick compared to much of the island.
3	Clean brewery tanks	Day 83 to Day 92 (10 days)	When Irma hit brewery had beer in their three tanks. Owners did not empty tanks to thoroughly clean them until electricity was restored.
4	First brew after hurricanes	Day 93 to Day 108 (16 days)	The owner started brewing as soon as the tanks were clean. He was able to use grain and other supplies he had stored in their garage, the only remaining part of their home, during Irma. Three new batches were brewed prior to reopening.
5	Brewery reopens and is sending beer to clients	Day 110 December 24, 2017	The brewery reopened and was sending beer to clients on Christmas Eve (December 24) 2017.

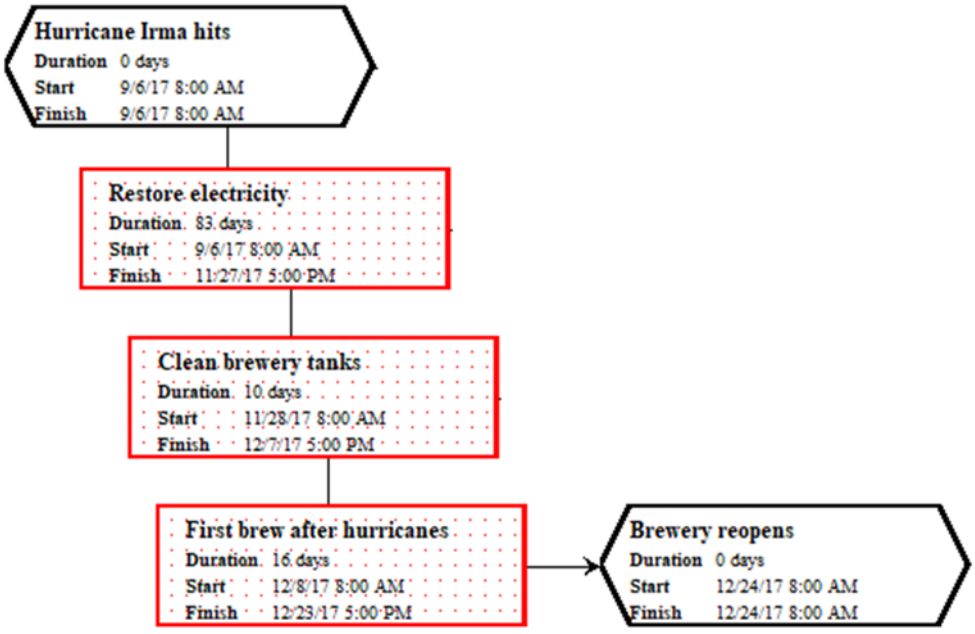


Figure 26. Critical path network diagram for reopening brewery

Near Critical Path

- **Brewing materials shortage:** Lack of brewing supplies never halted the process but was a potential concern. About six months after the hurricanes, there were shortages of CO_2 and yeast on St. Thomas, which are both essential to brewing. These materials primarily came from Puerto Rico which was decimated by Hurricane Maria. Had the shortages continued, brewing would have been interrupted.
- **Access:** The owners' home was completely destroyed, so they had to make it to the brewery to see if it was still standing so they could live there. They cleared trees and debris from the road as they traveled. The drive from their home to the brewery took about an hour and a half, almost six times longer than normal.
- **Damage Assessment:** The only damage to the brewery was a destroyed vent stack. The owners moved into their office for about eight weeks before relocating to an apartment.

Critical Path to Operating "Very close" to Normal

As the surrounding community recovers, tourism has slowly rebounded to the USVI and St. Thomas. After about two years, the brewery is operating "very close" to pre-hurricane levels. The major driver to surpassing pre-hurricane levels will be tourism driven by the reopening of major hotels and the rest of the tourism economy.

Appendix D: Outreach Process and Materials

Community Engagement Approach

Step 1. Perform Preliminary Research to Identify an Appropriate Universe of Hazards

- Perform literature review for earthquakes post 1989 and tornadoes, hurricanes (both major wind and flood events), and non-hurricane flood events post 2004.
- Identify events that resulted in substantial impacts to community water systems, school systems, and/or major businesses (at least two of the three).

Goal:

- Develop a honed-in list of events to explore as potential case studies.

Step 2. Network to Identify Promising Community Leads as Point Person

- Contact professional networks for folks with connections to communities impacted by the hazards. This is a relatively informal conversation describing the project goals, gathering general information about the community's impacts and recovery timeline, and identifying a potential community lead or point person.
- Send the 1-page project description document as a follow-up to provide written information about the project and our specific needs.

Goals:

- Learn more about the specific communities that would make the best case studies.
- Identify a strong lead within the community who can serve as a point person.

Step 3. Email Potential Point Person (Primary Community Contact)

- Send email: "Initial Email to Point Person" to potential point person identified in previous step (and copy your network contact), OR
- Ask the network contact from Step 2 to send an introductory email to make the connection, and follow up with the email in "Initial Email to Point Person."
- Attach the 1-page project description to the introductory email. This provides more information about the project and the type of information the team is looking for to develop case studies.

Goals:

- Help the potential point person better understand project.
- Set up an initial time to talk to further discuss project.

Step 4: Hold Phone Call with Point Person

- Hold a phone call with the primary contact, go over the 1-page project description, and answer any questions for the point person. See: "Call Agenda" for items to discuss on call.
- If the community sounds like it is a good fit for a case study, brainstorm with the point person to develop a list of key individuals (those familiar with the sequence and timing of activities critical to water system, school system, and/or major business recovery) to talk to during the team's visit to the selected case study area.

Goals:

- Clarify any questions the point person may have.
- Attain a better understanding if the community is appropriate for the case study. Was there was substantial damage to the at least two of the three targeted systems (water, schools, and/or large business)?
- Develop a list of key individuals in the selected community to interview for case studies.

Step 5: Email Key Individuals

- Send email "Initial Email to Water/School/Business Contact," OR
- Ask point person to make introduction to key individual and follow up with email: "Initial Email to Water/School/Business Contact."
- Attach one-pager to email.

Goal:

- Setup a time to meet in person.

Step 6: Meet in Person with Key Individuals and Possibly Point Person

- Travel to the area selected for case study and meet with the key individuals and possibly point contact if they are interested in being involved or are familiar with the steps to recovery.
- Conduct interviews using the Field Guides developed for each of the three social recovery endpoints.

Goals

- Conduct interviews with key individuals according to the Field Guide, and
- Establish a strong relationship with the primary by meeting face-to-face to make follow-up emails more effective.

Initial Email to Point Person

Goal: Setup a call to discuss work

Subject line: Time for a quick call to discuss [HAZARD] disaster recovery?

Dear NAME,

[XYZ Person] recommended we get in touch with you regarding an important project on disaster recovery.

The National Institute of Standards and Technology (NIST) Community Resilience Group is conducting work to better understand a community's path to recovery after a major disruptive event, such as an earthquake, flood, hurricane or tornado. NIST has contracted the team of Applied Research Associated (ARA) and Eastern Research Group (ERG) to help develop the information necessary to support this project under Ken Harrison (NIST). I have attached a 1-page project description for more technical details about what we're hoping to accomplish.

Goal of This Work: The goal of this project is to better understand the critical recovery activities and timelines for the following social recovery endpoints: (1) restoring water systems, (2) getting students back to school, and (3) getting a major business back in operation. Successfully identifying the critical path to recovery for these endpoints will help inform NIST community resilience modeling and planning guidance and, ultimately, help accelerate community recovery in future events.

What We Need from You:

If you have time for a quick phone call—no more than 30 minutes, it would be helpful to learn a little more about your community's recovery process and determine whether your community would be a good fit for the project.

Best regards,

SIGNATURE BLOCK

Initial Email to Water/School/Business Contact

Goal: Start scheduling in-person meetings with key individuals

Subject line: Scheduling time to meet about disaster recovery

CC: Point person [or have them make the introduction first and follow up with this email]

Dear NAME,

[POINT PERSON] recommended we get in touch with you regarding an important project on disaster recovery that we are working under contract to The National Institute of Standards and Technology (NIST) Community Resilience Group.

Based on our discussion with [POINT PERSON], we would very much like to meet with you in person to discuss your path to recovery after [X-DISASTER/EVENT.] Specifically, we're looking to better understand the sequence and timing of the critical activities needed for your [water system to resume normal operation, school system to reopen, or business to reopen].

We are hoping to travel to your area in [provide a month or range of weeks]. Would you be able to provide three to four days or windows of time during this period that would work best for a meeting? We'll need 1-2 hours of your time to gather the information we need for our project.

Successfully identifying the critical path to recovery will help inform NIST community resilience modeling and planning guidance and, ultimately, help accelerate community recovery in future events.

Best regards,

SIGNATURE BLOCK

Point Person Phone Call Agenda

- Brief introductions
- Contractor reviews one-pager, providing a brief 3-minute high-level project overview and what we're looking for in case studies
- Point person asks any questions on the overview
- Point person provides a high-level description of the recovery effort to determine fit for project
- Brainstorm possible key individuals to meet with for community water systems, school systems, and/or major businesses (at least two of the three)
- Discuss next steps

Appendix E: Water Systems Field Guide

Field Guide for Water System Recovery Modeling

This document provides forms and guidance that can be used to investigate and document the critical path to recovery of a water supply system following a disaster (e.g., earthquake, flood, or wind hazard event).

Step 1: Gather Basic Water System Information

Name of Water System: _____

Disaster Event (Name, Type, and Date): _____

System Size: _____
Average Daily Demand (MGD):_____ Employees: _____

Customers:
Residential: _____ Commercial: _____ Critical: _____
Wholesale: _____

Water Source(s):
Name: _____ Type: Reservoir, River, Aquifer, Other:_____

Treatment Plant(s):
Number: _____ Total Capacity (MGD): _____

Water Mains and Distribution Lines:
Water Mains: Materials: _____ Total Length: _____
Distribution Lines: Materials: _____ Total Length: _____

Notes:_____
_____
_____
_____
_____
_____
_____
_____
_____

Step 2. Identify Types and Durations of Disruption

Check Yes, No, or Unknown to the following statements regarding disruption types. Enter the total duration of the disruption relative to ***when the hazard began*** *in hours (h), days (d), weeks (w), or months (m), and any qualifying notes in the table below. Location and Data Source should reference location, contact and/or document number(s) in reference tables at end of field guide.* ***The goal of this is to provide context regarding the severity of the disruptions and start to get everyone thinking about the timeline, recovery path, and most applicable milestones heading into Step 3.***

Disruption	Yes, No, or Unknown	Duration h/d/w/m	Notes	Facilities Affected Facility ID(s)	Data Source Document or Contact Number
Raw water sources or conveyance systems disrupted					
Water treatment systems disabled					
Utilities interrupted					
Inventories or supplies were disrupted (e.g., chemicals)					
Water mains or treated water storage tanks damaged					
Water distribution lines damaged					
Employees unable to report to work					
Repair crews were not able to access damaged components					
Water quality impaired					
Temporary measures used (bottled water, temporary piping, boil water)					

Step 3: Select the Most Meaningful Recovery Milestones

Check three recovery milestones from the list below that were applicable and meaningful to the water system (or add some as "other" recovery milestones). It may be meaningful to select milestones representing "minimal," "functional," and "operational" (i.e., the 30%, 60%, and 90% recovery levels in the NIST CR Planning Guide). In Step 4, we will be determining the critical path to each of the three selected milestones.

- ❑ Source of **raw water** restored.
  Describe:_____
- ❑ **Water treatment plant(s)** open, but at reduced capacity
  Describe:_____
- ❑ **Water treatment plant(s)** open at full capacity
  Describe:_____
- ❑ **Storage tanks** and **water mains** functional for a portion of the service network
  Describe:_____
- ❑ **Storage tanks** and **water mains** functional for the entire service network
  Describe:_____
- ❑ **Distribution lines** functional for a portion of the service network
  Describe:_____
- ❑ **Distribution lines** functional for the entire service network
  Describe:_____
- ❑ Partial service restored with **reduced water pressure** and/or **boil water advisories**.
  Describe:_____
- ❑ Full service restored with **reduced water pressure** and/or **boil water advisories**.
  Describe:_____
- ❑ Full service restored with **normal water pressure** and **normal water quality**.
  Describe:_____
- ❑ Other:_____

Milestone Prompts:

1) Did loss of power delay restoration of services?
2) Did loss of communications delay restoration of services?
3) Did road closures delay restoration of services?
4) Did insufficient personnel delay restoration of services?
5) Did insufficient replacement part delay restoration of services?
6) Did insufficient heavy or light equipment delay restoration of services?
7) Were any interim solutions (alternative sources, temporary lines, bottled water, etc.) put in place?
8) Did damage inspections, permitting, or engineering delay restoration of services?
9) Did water quality testing delay restoration of services?

Step 4. Map Out Critical Path to Recovery
This step should be performed for up to three milestones identified in Step 3, beginning with the earliest milestone.

Supplies:
Note cards (5'' x 7''), pen, a white board with red and black marker OR a couple of pieces of white paper (poster size—about 3 feet wide) with a red and black marker.

Activity Description:
For a high-level visualization of this mapping activity, see Figure 27.
For information on how to fill out the front of note cards, see Tasks 1-6 and Figure 28.
For information on how to fill out the back of note cards, see Task 8 and Figure 29.

Task 1. Select a milestone/interim milestone from Step 3, write the name of the milestone on a notecard, and put at the far right of your board/paper.

Task 2. Ask the question, "**What activity (or activities) needed to be done *immediately* before this milestone could happen?**" (i.e., what was the dependency leading to this milestone?). For the activity or activities you identified, write 1) the activity name, and 2) the start time, end time, and duration of the activity on the note card. Place these notecards to the left of the milestone and draw black arrows from the note card to the milestone. *Example: this is "I" and "G" in Figure 27* .

Task 3. Similar to Task 2 for each activity notecard you just placed, ask the question, "***What activity (or activities) needed to be done immediately before this activity could happen***?" For the activity or activities you identified, write 1) the activity name, and 2) the start time, end time, and duration of the activity on the note card. Place these notecards to the left of the activity and draw black arrows from the note card to the activity this is a predecessor of. *Example: this is "H" before "I" and both "F" and "C" before "G" in Figure 27.*

Task 4. Repeat Task 3 until all critical or near-critical paths reach back to the hazard event or a previously mapped milestone.

Task 5. For all the possible paths from hazard to milestone, sum the timeline. For the path with the longest duration, **draw red arrows to indicate the critical path** (and mark the front of those note cards with a "CP"). Also highlight any **near-critical paths to capture** for the project (those with similar timelines that could become the critical path if something were to go wrong). Mark the front of those cards with an "NC".

Task 6. Confirm the critical path for each activity along the critical path by asking "if this activity [along the critical path] was delayed, would it have moved back the start time of this next activity [along the critical path]?" The answer should be **yes** for each item on the critical path. Move from left to right, beginning with the first activity along the path. For example, ask if a delay in activity D in Figure 27 would move back the start time of activity E. Ask the same about E relative to F, F relative to G, and G relative to the milestone. By definition, we should see a delay in the first activity impact each subsequent activity (and the milestone recovery date) accordingly if it's on the critical path.

Task 7. Assign a letter (make large and dark) to activities on the critical and near-critical path cards (starting with letter A). If there are other non-critical path activities you want to document, assign a letter to those cards as well.

Task 8. Take a photo of the entire note card activity (ensure you can see note card letters in photo).

Task 9. On the back side of the **critical path** and **near-critical path** note cards, add the information shown in Figure 29 to provide more context about what held up or could have sped up activities.

Task 10. Keep all the notecards so you can document in the report.

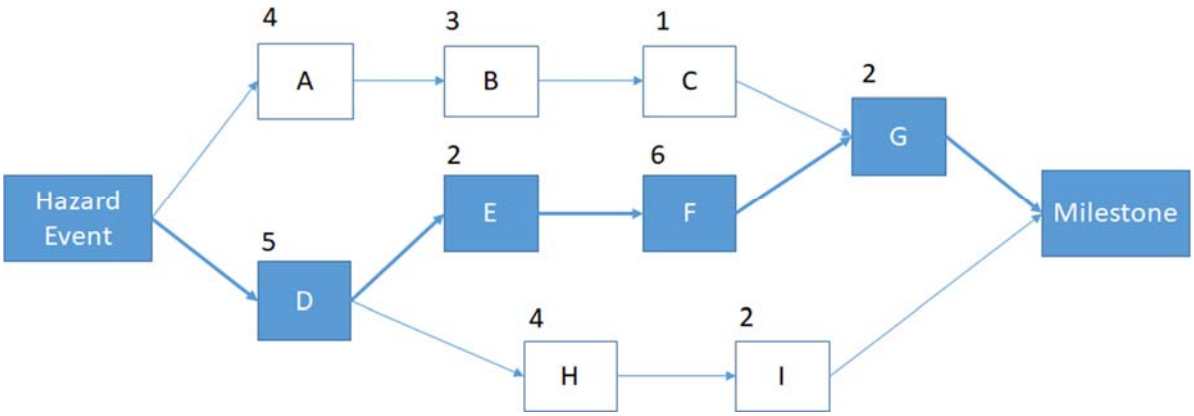


Figure 27. Activity cards arranged to show the critical path to recovery.

Letter	Activity Description			Critical Path Activity?
				__ Critical __ Near-Critical
Start Time	**End Time**	**Duration** h/d/w/m	**Predecessors** Activity Letters	**Data Sources** Doc. or Contact Number(s)
Notes:				

Figure 28. Front side of activity card.

Why did this activity hold up the recovery process?	What decisions or actions (identified after disaster occurrence) slowed this activity?
What decisions or actions taken prior to disaster occurrence sped up this activity?	**What decisions or actions (identified after disaster occurrence) could have sped up activity?**

Figure 29. Back side of activity card to be completed for critical and near-critical activities.

Reference Information: Contact Information

As contacts are identified, add them to the table below to reference in critical path analysis. The second table provides some recommended agencies and positions to contact.

Contact Number	Name	Position	Phone	Email	Documents Discussed	Date Contacted
C1						
C2						
C3						
C4						
C5						
C6						
C7						
C8						
C9						
C10						

General Sources of Information	
Water System	System Manager/Superintendent/Director
	Plant Manager(s)
	Public Relations Officer (e.g., press releases)
	Chief Operations Officer
	Human Resources
	Chief Financial Officer
Local Government	City Manager/Mayor
	Emergency Manager (ESF #3 – Public Works and Engineering)
	City Engineer
	Director of Department of Public Works (DPW)
	Sanitation Department
	Health Department
	Fire Department
State Government	Water Resources Commission
	Department of Environmental Quality (or equivalent)
	Department of Health and Human Services
Federal Government	Federal Emergency Management Agency (FEMA)
	Environmental Protection Agency (EPA)

Reference Information: List of Water System Facilities and Components

As system facilities or components are discussed, add them to the table below to reference in critical path analysis.

ID Number	Facility or Component Name	Address
W1		
W2		
W3		
W4		
W5		
W6		
W7		
W8		
W9		
W10		
W11		
W12		
W13		
W14		
W15		
W16		
W17		
W18		
W19		
W20		

Reference Information: Documents

As documents are collected, add them to the table below to reference in critical path analysis.

Document Number	Title	Type	Contact/Source	Date Acquired
D1				
D2				
D3				
D4				
D5				
D6				
D7				
D8				
D9				
D10				
D11				
D12				
D13				
D14				
D15				
D16				
D17				
D18				
D19				
D20				

Appendix F: Schools Field Guide

Field Guide for School System Recovery Modeling

This document provides forms and guidance that can be used to investigate and document the critical path to recovery of a school system following a disaster (e.g., earthquake, flood, or wind hazard event).

Step 1: Gather Basic School System Information

Name of School System:

_____

Disaster Event (Name, Type, and Date):

_____

Built Environment:
Total number of campuses: _____

Utility provider(s): Water: _____ Electric power: _____

Natural gas or heating fuel: _____ Communications: _____

Students and Employees:

_____

Total enrollment:

_____

Total number of system employees:

_____

Operations:
School calendar type (select one): Traditional Year-Round Other (explain):_____

Notes:_____

Step 2. Identify Types and Durations of Disruption

Check Yes, No, or Unknown to the following statements regarding disruption types. Enter the total duration of the disruption relative to ***when the hazard began*** *in hours (h), days (d), weeks (w), or months (m), and any qualifying notes in the table below. Location and Data Source should reference location, contact and/or document number(s) in reference tables at end of field guide.* ***The goal of this is to provide context regarding the severity of the disruptions and start to get everyone thinking about the timeline, recovery path, and most applicable milestones heading into Step 3.***

Disruption	Yes, No, or Unknown	Duration h/d/w/m	Notes	Campus(es) Affected Campus Number(s)	Data Source Document or Contact Num.
School buildings were closed for safety reasons					
Utilities were interrupted					
School buildings were closed for cleanup					
Students could not access facilities					
Employees could not access facilities					
Schools were closed for other reasons (explain)					
School(s) operated on a reduced schedule					
Student enrollment fell compared to pre-disaster levels					
Curriculum was reduced compared to pre-disaster levels					
Extra-curricular activities were reduced compared to pre-disaster levels					

Step 3: Select the Most Meaningful Recovery Milestones

Check three recovery milestones from the list below that were applicable and meaningful to the school district (or add some as "other" recovery milestones). It may be meaningful to select milestones representing "minimal," "functional," and "operational" (i.e., the 30%, 60%, and 90% recovery levels in the NIST CR Planning Guide). In Step 4, we will be determining the critical path to each of the three selected milestones.

- ❑ Schools open with ***temporary facilities*** in place (e.g., trailers, repurposed buildings, etc.).
  Describe:_____
- ❑ ***Permanent facilities*** are repaired or built, deemed safe, and utilities have been restored.
  Describe:_____
- ❑ Schools are ***fully staffed***.
  Describe:_____
- ❑ Classes resume with ***reduced hours*** or on ***split schedule***.
  Describe:_____
- ❑ Classes resume on a ***regular schedule***
  Describe:_____
- ❑ ***Attendance*** returns to 95% or more of enrollment.
  Describe:_____
- ❑ ***Enrollment*** is at or near pre-disaster levels.
  Describe:_____
- ❑ All pre-event ***courses and extra-curricular activities*** have resumed.
  Describe:_____
- ❑ Other:_____
- ❑ Other:_____
- ❑ Other:_____

Milestone Prompts:

1) Were any buildings structurally unsafe?
2) Was access to any utility affected or disrupted?
3) Were any indoor/outdoor pollutants or hazards at unsafe levels?
4) Did road closures delay reopening of schools?
5) Were transportation resources (school/public buses) available?
6) Was a decline in enrollment or attendance experienced?
7) Did a significant portion of the population relocate outside of the school district?
8) Did staff shortages occur (e.g., administrators, teachers, janitors, cafeteria workers, etc.)?
9) Were any interim solutions (e.g., temporary classrooms, reduced schedules, etc.) put in place?
10) Did all pre-event courses and extra-curricular activities resume?

Step 4. Map Out Critical Path to Recovery
This step should be performed for up to three milestones identified in Step 3, beginning with the earliest milestone.

Supplies:
Note cards (5'' x 7''), pen, a white board with red and black marker OR a couple of pieces of white paper (poster size—about 3 feet wide) with a red and black marker.

Activity Description:
For a high-level visualization of this mapping activity, see Figure 30.

For information on how to fill out the front of note cards, see Tasks 1-6 and Figure 31.

For information on how to fill out the back of note cards, see Task 8 and Figure 32.

Task 1. Select a milestone/interim milestone from Step 3, write the name of the milestone on a notecard, and put at the far right of your board/paper.

Task 2. Ask the question, "**What activity (or activities) needed to be done *immediately* before this milestone could happen?**" (i.e., what was the dependency leading to this milestone?). For the activity or activities you identified, write 1) the activity name, and 2) the start time, end time, and duration of the activity on the note card. Place these notecards to the left of the milestone and draw black arrows from the note card to the milestone. *Example: this is "I" and "G" in Figure 30.*

Task 3. Similar to Task 2 for each activity notecard you just placed, ask the question, "***What activity (or activities) needed to be done immediately before this activity could happen***?" For the activity or activities you identified, write 1) the activity name, and 2) the start time, end time, and duration of the activity on the note card. Place these notecards to the left of the activity and draw black arrows from the note card to the activity this is a predecessor of. *Example: this is "H" before "I" and both "F" and "C" before "G" in Figure 30.*

Task 4. Repeat Task 3 until all critical or near-critical paths reach back to the hazard event or a previously mapped milestone.

Task 5. For all the possible paths from hazard to milestone, sum the timeline. For the path with the longest duration, **draw red arrows to indicate the critical path** (and mark the front of those note cards with a "CP"). Also highlight any **near-critical paths to capture** for the project (those with similar timelines that could become the critical path if something were to go wrong). Mark the front of those cards with an "NC".

Task 6. Confirm the critical path for each activity along the critical path by asking "if this activity [along the critical path] was delayed, would it have moved back the start time of this next activity [along the critical path]?" The answer should be **yes** for each item on the critical path. Move from left to right, beginning with the first activity along the path. For example, ask if a delay in activity D in Figure 30 would move back the start time of activity E. Ask the same about E relative to F, F relative to G, and G relative to the milestone. By definition, we should see a delay in the first activity impact each subsequent activity (and the milestone recovery date) accordingly if it's on the critical path.

Task 6. Assign a letter (make large and dark) to activities on the critical and near-critical path cards (starting with letter A). If there are other non-critical path activities you want to document, assign a letter to those cards as well.

Task 7. Take a photo of the entire note card activity (ensure you can see note card letters in photo).

Task 8. On the back side of the **critical path** and **near-critical path** note cards, add the information shown in Figure 32 below to provide more context about what held up or could have sped up activities.

Task 9. Keep all the notecards so you can document in the report.

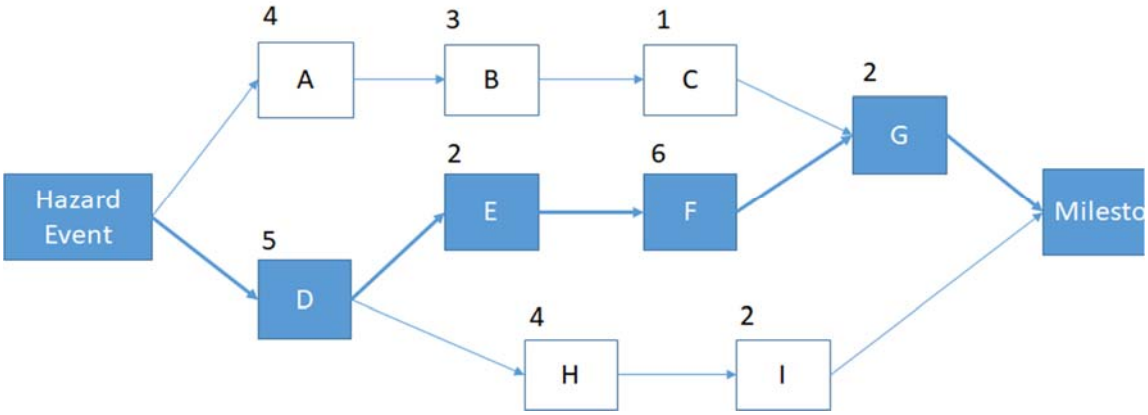


Figure 30. Activity cards arranged to show the critical path to recovery.

Letter	Activity Description			Critical Path Activity?
				_ Critical _ Near-Critical
Start Time	**End Time**	**Duration** h/d/w/m	**Predecessors** Activity Letters	**Data Sources** Doc. or Contact Number(s)
Notes:				

Figure 31. Front side of activity card.

Why did this activity hold up the recovery process?	What decisions or actions (identified after disaster occurrence) slowed this activity?
What decisions or actions taken prior to disaster occurrence sped up this activity?	**What decisions or actions (identified after disaster occurrence) could have sped up activity?**

Figure 32. Back side of activity card to be completed for critical and near-critical activities.

Reference Information: Contact Information

As contacts are identified, add them to the table below to reference in critical path analysis. A table of recommended agencies and positions to contact for information is provided.

Contact Number	Name	Position	Phone	Email	Documents Discussed	Date Contacted
C1						
C2						
C3						
C4						
C5						
C6						

General Sources of Information	
School System	District Superintendent
	Principal(s), Vice Principal(s), Administration
	School Board
	Director of: Building Operations, Buildings and Grounds, Facilities Design and Construction
	Human Resources Department
	District Business/Finance Manager
	Transportation Director
	Public Relations
Government **Local, State, Federal**	Building Department
	Emergency Manager
	Department of Education
	Department of Health and Human Services
	Department of Transportation
	Federal Emergency Management Agency (FEMA)

Reference Information: List of School Campuses

Campus Number	Campus Name	Address
S1		
S2		
S3		
S4		
S5		
S6		
S7		
S8		
S9		
S10		
S11		
S12		
S13		
S14		
S15		
S16		
S17		
S18		
S19		
S20		

Reference Information: Documents

As documents are collected, add them to the table below to reference in critical path analysis.

Document Number	Title	Type	Contact Source	Date Acquired
D1				
D2				
D3				
D4				
D5				
D6				
D7				
D8				
D9				
D10				
D11				
D12				
D13				
D14				
D15				
D16				
D17				
D18				
D19				
D20				

Appendix G: Business Field Guide

Field Guide for Business Recovery Modeling

This document provides forms and guidance that can be used to investigate and document the critical path to recovery of businesses following a disaster (e.g., earthquake, flood, or wind hazard event).

Step 1. Gather Basic Business Information

Name of Business: _____

Type of Business: _____

Disaster Event (Name, Type, and Date):

_____

Built Environment:
Year built: _____
Utility provider(s): Water: _____ Electric power: _____
Natural gas or heating fuel: _____ Communications: _____

Employees at Site of Business
Approximate # employees before event ____ Approximate # current employees _____

Notes:

_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____

Step 2. Identify Types and Durations of Disruption

Check Yes, No, or Unknown to the following statements regarding disruption types. Enter the total duration of the disruption relative to ***when the hazard began*** *in hours (h), days (d), weeks (w), or months (m), and any qualifying notes in the table below. Location and Data Source should reference location, contact and/or document number(s) in reference tables at end of field guide.* ***The goal of this is to provide context regarding the severity of the disruptions and start to get everyone thinking about the timeline, recovery path, and most applicable milestones heading into Step 3.***

Disruption	Yes, No, or Unknown	Duration h/d/w/m	Notes	Location Location Number(s)	Data Source Document or Contact Num.
We were closed for business.					
Our building was not safe and functional, and we could not open.					
Our utilities were interrupted.					
Our inventory or supplies were interrupted.					
Our employees could not access our business.					
Our customers could not access our business.					
Our revenue or sales fell compared to pre-disaster sales.					
Our profits fell compared to pre-disaster profits.					

Step 3. Select Up to Three Applicable and Meaningful Recovery Milestones

Check three recovery milestones from the list below that were applicable and meaningful to the business (or add some as "other" recovery milestones). It may be meaningful to select milestones representing "minimal," "functional," and "operational" (i.e., the 30%, 60%, and 90% recovery levels in the NIST CR Planning Guide). In Step 4, we will be determining the critical path to each of the three selected milestones.

- ❑ Business opens back up with ***temporary buildings/structures/partial facility*** (e.g., trailers, re-purposed, partial facility or some buildings repaired to allow for opening).
  Describe:_____
- ❑ Business opens back up with ***reduced*** hours (e.g., reduced or split schedule, fewer shifts).
  Describe:_____
- ❑ Business opens back up with ***limited*** services, products, or equipment availability.
  Describe:_____
- ❑ Business opens back up with a ***limited*** supply chain.
  Describe:_____
- ❑ Entire facility is repaired.
  Describe:_____
- ❑ Business operates with ***regular*** hours.
  Describe:_____
- ❑ Business operates with ***full-level*** of staff.
  Describe:_____
- ❑ Business operates with ***full-level*** of services, products, or equipment availability.
  Describe:_____
- ❑ Business operates with ***full-****supply chain*.
  Describe:_____
- ❑ Business resumes ***normal operations*** (as defined by business).
  Describe:_____
- ❑ Pre-disaster level of revenue, customer traffic, or productivity is reached/exceeded.
  Describe:_____
- ❑ Pre-disaster level of profitability is reached/exceeded.
  Describe:_____
- ❑ Other:_____

Milestone Prompts:

1) Were any buildings/facilities structurally unsafe and need to be repaired?
2) Was access to any utility affected or disrupted?
3) Did road closures cause issues for employees or customers to access the business?
4) Did transportation obstacles impact your supply chain?
5) Were some staff not able to return (e.g., relocation) once the business opened back up?
6) Did staff shortages occur?
7) Were any interim solutions (e.g., temporary facilities, limited services) put in place?
8) Did the number of customers decrease dramatically after the event (e.g., less tourism, less foot traffic in the area)?

Step 4. Map Out Critical Path to Recovery
This step should be performed for up to three milestones identified in Step 3, beginning with the earliest milestone.

Supplies:
Note cards (5'' x 7''), pen, a white board with red and black marker OR a couple of pieces of white paper (poster size—about 3 feet wide) with a red and black marker.

Activity Description:
For a high-level visualization of this mapping activity, see **Figure 33.**
For information on how to fill out the front of note cards, see **Tasks 1-6** and **Figure 34**.
For information on how to fill out the back of note cards, see **Task 8** and **Figure 35**.
Task 1. Select a milestone/interim milestone from Step 3, write the name of the milestone on a notecard, and put at the far right of your board/paper.

Task 2. Ask the question, "**What activity (or activities) needed to be done *immediately* before this milestone could happen?**" (i.e., what was the dependency leading to this milestone?). For the activity or activities you identified, write 1) the activity name, and 2) the start time, end time, and duration of the activity on the note card. Place these notecards to the left of the milestone and draw black arrows from the note card to the milestone. *Example: this is "I" and "G" in Figure 33.*

Task 3. Similar to Task 2 for each activity notecard you just placed, ask the question, "***What activity (or activities) needed to be done immediately before this activity could happen***?" For the activity or activities you identified, write 1) the activity name, and 2) the start time, end time, and duration of the activity on the note card. Place these notecards to the left of the activity and draw black arrows from the note card to the activity this is a predecessor of. *Example: this is "H" before "I" and both "F" and "C" before "G" in Figure 33.*

Task 4. Repeat Task 3 until all critical or near-critical paths reach back to the hazard event or a previously mapped milestone.

Task 5. For all the possible paths from hazard to milestone, sum the timeline. For the path with the longest duration, **draw red arrows to indicate the critical path** (and mark the front of those note cards with a "CP"). Also highlight any **near-critical paths to capture** for the project (those with similar timelines that could become the critical path if something were to go wrong). Mark the front of those cards with an "NC".

Task 6. Confirm the critical path for each activity along the critical path by asking "if this activity [along the critical path] was delayed, would it have moved back the start time of this next activity [along the critical path]?" The answer should be **yes** for each item on the critical path. Move from left to right, beginning with the first activity along the path. For example, ask if a delay in activity D would move back the start time of activity E. Ask the same about E relative to F, F relative to G, and G relative to the milestone. By definition, we should see a delay in the first activity impact each subsequent activity (and the milestone recovery date) accordingly if it's on the critical path.

Task 7. Assign a letter (make large and dark) to activities on the critical and near-critical path cards (starting with letter A). If there are other non-critical path activities you want to document, assign a letter to those cards as well.

Task 8. Take a photo of the entire note card activity (ensure you can see note card letters in photo).

Task 9. On the back side of the **critical path** and **near-critical path** note cards, add the information shown in Figure 35 below to provide more context about what held up or could have sped up activities.

Task 10. Keep all the notecards so you can document in the report.

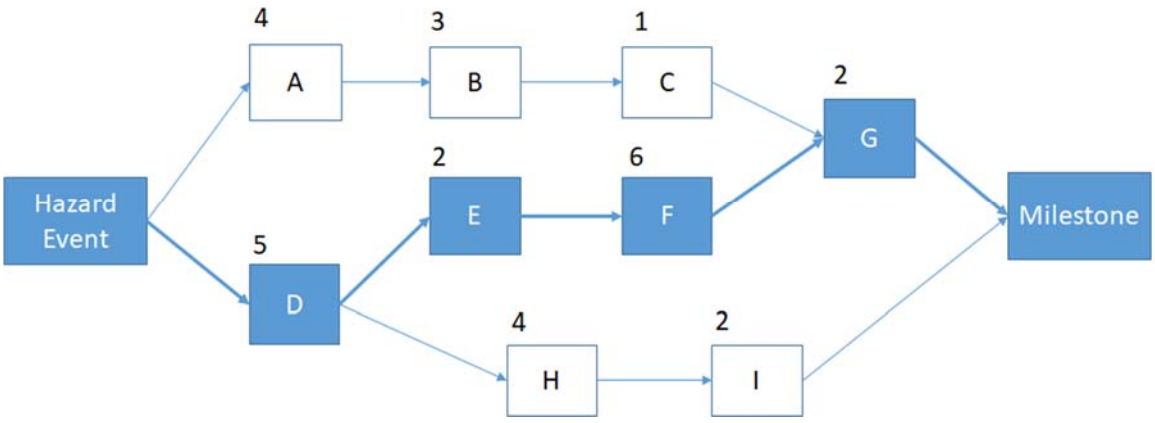


Figure 33. Activity cards arranged to show the critical path to recovery.

Letter	Activity Description			Critical Path Activity?
				__ Critical __ Near-Critical
Start Time	**End Time**	**Duration** h/d/w/m	**Predecessors** Activity Letters	**Data Sources** Doc. or Contact Number(s)
Notes:				

Figure 34. Front side of activity card.

Why did this activity hold up the recovery process?	What decisions or actions (identified after disaster occurrence) slowed this activity?
What decisions or actions taken prior to disaster occurrence sped up this activity?	**What decisions or actions (identified after disaster occurrence) could have sped up activity?**

Figure 35. Back side of activity card to be completed for critical and near-critical activities.

Reference Information: Contacts

As contacts are identified, add them to the table below to reference in critical path analysis. The second table provides some recommended positions to contact.

Contact Number	Name	Position	Phone	Email	Documents Discussed	Date Contacted
C1						
C2						
C3						
C4						
C5						
C6						
C7						
C8						

General Sources of Information	
Business	Chief Executive Officer (CEO)
	Chief Operations Officer (COO)
	Chief Technology Officer (CTO)
	President
	Vice President(s)
	Human Resources Manager
	Other Company Executives
	Maintenance Staff
Non-Business	Property Management Company
	Property Manager
	Building Facilities

Reference Information: List of Business Locations

As different business locations are identified and discussed, add them to the table below to reference in critical path analysis.

ID Number	Building or Facility Name	Address
B1		
B2		
B3		
B4		
B5		
B6		
B7		
B8		
B9		
B10		
B11		
B12		
B13		
B14		
B15		
B16		
B17		
B18		
B19		
B20		

Reference Information: Documents

As documents are collected, add them to this table to reference in questions above

Document Number	Title	Type	Contact/Source	Date Acquired
D1				
D2				
D3				
D4				
D5				
D6				
D7				
D8				
D9				
D10				
D11				
D12				
D13				
D14				
D15				
D16				
D17				
D18				
D19				
D20				