Building a Resilient Telecommunications Sector in Puerto Rico in the Aftermath of Hurricanes Irma and Maria

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Abstract

In September 2017, following two catastrophic hurricanes, Puerto Rico's wireline, wireless and cable networks were rendered largely inoperable. As this article will illustrate, the causes of this devastating failure of the telecommunications sector were not attributable to Hurricanes Irma and Maria alone. The hurricanes revealed the fragility of Puerto Rico's telecommunications infrastructure, which failed, leaving the majority of Puerto Rican citizens without a means to communicate by phone or by Internet or to reach 911 for emergency services for weeks or months. This article will also sum-marize the 33 courses of action (COAs) for rebuilding the telecom-munications sector that were proposed by the Homeland Security Operational Analysis Center, a Federally Funded Research and De-velopment Center (FFRDC) operated by the RAND Corporation and adopted by the government of Puerto Rico. These COAs were prepared as part of the Congressionally mandated Puerto Rico eco-nomic and disaster recovery plan. Even though significant progress has been made toward recovery in Puerto Rico, substantial invest-ment is still required to achieve a resilient and robust telecommu-nications sector. The estimated cost for the 33 COAs was $3.2 bil-lion. The overall cost estimate for the Puerto Rico recovery plan, including all sectors, was $139 billion.

Keywords: Telecommunications, Recovery, Infrastructure, Puerto Rico, Courses of Action

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Introduction

On September 6, 2017, the main island of Puerto Rico experienced tropical storm force winds from Hurricane Irma. The island received 10 to 15 inches of rainfall from Irma, particularly in its central mountainous region. Rain and strong winds caused minor damage to trees and man-made structures as well as a near-total loss of electrical power and water for several days. Two weeks later, on September 20, Hurricane Maria made landfall in the southeast of the main island of Puerto Rico. The center of this Category 4 hurricane crossed Puerto Rico from the southeast to the northwest of the island and finally moved offshore, as shown in Figure 1. Also, as illustrated in Figure 1, extreme winds battered the island. Hurricane Maria was the most intense hurricane to strike Puerto Rico since the San Felipe Hurricane of 1928. Hurricane Maria caused unprecedented and extensive damage throughout the island.

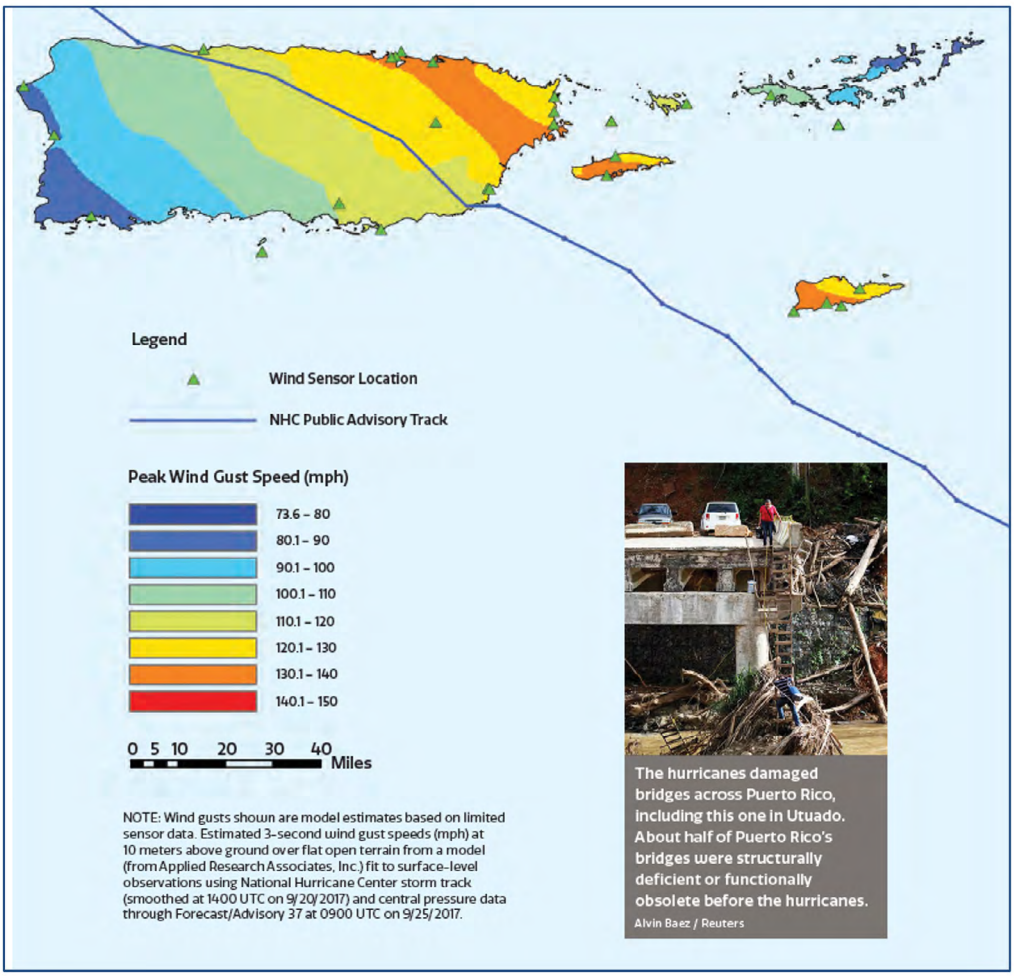

Figure 1. Path of Hurricane Maria, Peak Wind Gust Speeds and Example of Damage

The telecommunications sector, especially, suffered island-wide devastation. Prior to these hurricanes, the state of the island's telecommunications infrastructure was not conducive to withstanding a catastrophe of this magnitude. The pre-storm fragility of the telecommunications infrastructure and the intensity of the hurricanes led to the wide-spread failure of telecommunications networks throughout Puerto Rico. This failure had a major impact on the island's government, emergency services, and economy—retail stores, banks, pharmaceutical companies, groceries, restaurants, transportation and many other businesses—with dire consequences for Puerto Rico residents. The failure of telecommunications infrastructure prevented the Government of Puerto Rico (GPR) from communicating essential information to its citizens, substantially increased the risk to public safety, and contributed to the shutdown of Puerto Rico's economy.

SOURCE: Burns & McDonnell.
NOTE: Note the pole in the center of the wooded area that is broken off at the base and conductors (wires) laying in the grass at its base. This pole was one of 14 in a row that were downed in this wooded area.

Figure 2. Example of Downed Poles

The telecommunication links of the wireline infrastructure, including backhaul for cellular services, consisted predominantly of aerial fiber-optic cable. Because it is exposed to the elements, this type of cable is more susceptible to storm damage than buried fiber-optic cable. Moreover, in Puerto Rico, aerial cable was supported by poles owned primarily by the electric utility, the Puerto Rico Electric Power Authority (PREPA), and many of these poles were old and not well maintained. A typical example of downed poles is shown in Figure 2. The hurri-

canes damaged over 90 percent of the private telecommunications infrastructure, primarily antennas and aerial cable (FEMA, 2017). Furthermore, in the initial aftermath of the hurricanes, 95 percent of cellular sites in Puerto Rico were out of service, and 48 of the 78 municipalities had lost all service from their cellular sites (FCC, 2017).

The 911 centers in Puerto Rico depended on wireline infrastructure to relay calls from residents in need of emergency services to first responders (police, fire, and emergency medical services). These centers also relied on five public-safety telecommunication systems and two microwave networks, which were also substantially damaged by the hurricanes. Failures in the wireline infrastructure and in the public-safety systems and microwave networks hampered emergency response efforts when Puerto Rico residents needed them the most. Many of the people who were fortunate enough to reach a 911 center did not receive the required fire, police or medical services due to the lack of emergency communications linkages across municipalities and agencies.

The damage caused by the hurricanes to San Juan's submarine cable primary landing station resulted in a serious handicap for Puerto Rico's off-island communications. The submarine cable-related infrastructure was the main high-capacity, off-island communications capability for the island. Submarine (i.e., undersea) fiber-optic cables around Puerto Rico and their associated infrastructure are providers of essential high-capacity communication links between Puerto Rico, the mainland United States, and other parts of the world. However, they presented a single-point-of-failure vulnerability. That was because all submarine cable landing stations were located in the San Juan metropolitan area and there were no alternative routing options elsewhere in Puerto Rico.

Finally, the entire telecommunications infrastructure strongly depended on a reliable electrical grid to maintain power to the cellular sites and telecommunications networks during and after an emergency, a vulnerability that was exacerbated by conditions at Puerto Rico Electric Power Authority (PREPA). The catastrophic failure of PREPA's electrical grid and its very delayed repair forced telecommunication providers to make use of fuel-based generators to power up their cellular sites for many months. These generators were designed for emergency outages of hours or days, not months, and created a logistical nightmare for cellular carriers to provide fuel to keep them in service.

Even as antennas, poles and aerial fiber-optic cable were repaired and commercial communications started being restored, enduring difficulties remained for many residents and businesses. For example, voice and text messaging services were often restored before data services. Thus, Puerto Rico residents had limited ability to apply for relief through the Federal Emergency Management Agency (FEMA) of the U.S. Department of Homeland Security, because they lacked data services and access to the Internet. Moreover, lack of communications and Inter-

net connectivity prevented businesses from contacting employees, fulfilling orders and communicating effectively with headquarters, subsidiaries, suppliers and customers located in the mainland U.S. Finally, just as the telecommunications infrastructure was critically dependent on the electrical grid, residents without electric power could not benefit from restored telecommunications networks if their cellular devices could not be charged.

The work presented in this article concerns the restoration and improvement of the telecommunications sector in Puerto Rico. It was conducted during the development of the Puerto Rico economic and disaster recovery plan, which was mandated by the U.S. Congress in accordance with the *Bipartisan Budget Act of 2018*. The overall economic and recovery plan, *Transformation and Innovation in the Wake of Devastation: An Economic and Disaster Recovery Plan for Puerto Rico,* was delivered to Congress on August 8, 2018.

The article presents an introduction to the telecommunications sector in Puerto Rico and its status prior to Hurricanes Irma and Maria, briefly describes the impact of the hurricanes on this sector, and summarizes the methodology and 33 courses of action (COAs) developed for the recovery of the sector.

Puerto Rico's Telecommunications Sector Prior to the Hurricanes

The telecommunications infrastructure of Puerto Rico was made up of different technologies serving both the private and public sectors, and networks that interconnected to provide voice and data communications. These technologies and networks required the provision of continuous and sufficient power via the electrical grid to function at optimal performance.

The private telecommunications infrastructure included wireline service provided by Claro[1] (the Public Switched Telephone Network or PSTN); cellular service provided by AT&T, T-Mobile, Claro, and PR Wireless;[2] Internet service provided by means of cable (Liberty Cablevision), DSL (e.g., Claro, WorldNet), fiber (e.g., Optico Fiber), and fixed wireless (e.g., IP Solutions, Caribe.net, Inteco, Neptuno Networks). Liberty Cablevision of Puerto Rico was the only cable provider

1 Telecommunications services in Puerto Rico were provided since 1974 by government-owned Puerto Rico Telephone Company (PRTC). In 1997, the Puerto Rico legislature enacted legislation to allow the sale of PRTC, and a year later GTE purchased PRTC from the Puerto Rico Government. Bell Atlantic, now Verizon Communications, acquired GTE in 2000. PRTC remained as a subsidiary of Verizon Communications until it was purchased by América Móvil in 2007. América Móvil rebranded many of PRTC's services in 2011 and 2013 under the name "Claro." Claro is the only incumbent local exchange carrier (ILEC) in Puerto Rico. It currently provides residential wireline, wireless, broadband digital subscriber line (DSL), dial-up services, and Internet protocol television, as well as services to business, government, and enterprises in Puerto Rico.

2 In November 2017, Sprint and Open Mobile formed a joint venture, PR Wireless, LLC. The merger was approved by the Federal Communications Commission and by Puerto Rico authorities (Kantrow-Vázquez, 2017).

in the island. Submarine cable infrastructure (including landing stations located in the San Juan metropolitan area) interconnected Puerto Rico with destinations outside of Puerto Rico and delivered international calls and data to the island. It also served as a high-capacity telecommunications relay between the mainland U.S. and other parts of the world (e.g., South America). Companies like Crown Castle, American Tower, Innovatel, and SBA provided cell towers and other infrastructure needed to mount radios and antennas. Finally, PREPA Networks provided services to telecommunication carriers and businesses throughout Puerto Rico.[3]

There were five public-safety telecommunications systems, relying on two island-wide microwave networks:

- Puerto Rico Police Department (PRPD) P25 Trunk System, that provided statewide radio coverage to police, fire, health, and other entities.
- PRPD SmartZone, for police use only, that operated in the San Juan metropolitan area.
- Emergency Medical Service System, that used an Ultra-high Frequency (UHF), analog, conventional system operating from five radio frequency (RF) sites, to provide communications capabilities for pre-medical care and emergency transport to hospitals.
- Puerto Rico Emergency Management Agency (PREMA) system, that used a Very High Frequency (VHF) system to provide day-to-day mobile radio communications between municipalities and PREMA.
- Interoperability System that was a cross-band interoperability system operated from eight RF sites that could support VHF, UHF, and 700 and 800 megahertz (MHz) radio traffic, to provide statewide communications in emergency or urgent situations (tsunamis, hurricanes, earthquakes, etc.).

Geography, population density and industrial location had a major influence on where the telecommunications infrastructure was concentrated. The result was that infrastructure density was greatest in and around metropolitan San Juan, where the majority of the population resides, near the coasts, where the terrain is flat, and in the West/Northwest region, where many pharmaceutical and aerospace companies are located. The main fiber-optic cable backhaul followed the highways that encircle the island, approximately parallel to the coast. The center of the island consists of mountainous terrain with lower population density. It had a much lower density of telecommunications sites, likely due to the obvious problems with building infrastructure in difficult terrain, and lower incentives for private investment when the potential customer base is not sufficiently large.

3 PREPA Networks also provides international connectivity to the U.S. (Miami, New York, and the Caribbean Islands).

Prior to the hurricanes, wireless communications in Puerto Rico far exceeded landline usage. About 99% of Puerto Rico residents had access to cellular service (FCC 18-10 2018), and only 20% of households had landline telephone services (FEMA, 2017).[4]

There were two Public Safety Answering Points (PSAPs) in Puerto Rico, the primary and the backup PSAPs.[5] When traffic volume was too high to be handled solely by the primary PSAP or when that PSAP was not operational, calls were routed to the backup PSAP. Emergency services communications relied on the public switched telephone network (PSTN) via a two-call process. The first call consisted of the person in need calling a PSAP, where the operator gathered the relevant information from the caller and entered it into the Computer Aided Dispatch (CAD) system. The PSAP operator then decided what type of emergency service was needed (police, fire, or medical help), and found out what district or municipal office responsible for dispatch was closest to the location of the caller. The second call went from the PSAP operator to that district or municipal office. The next step was for that office to dispatch a police patrol, an ambulance or a fire truck via Land Mobile Radio (LMR), or via one of the two microwave networks. The two-call process made emergency service communications more vulnerable to PSTN failures.

Many factors contributed to why the telecommunications infrastructure in Puerto Rico was not capable of withstanding a hurricane the magnitude of Maria. First, the preponderance of aerial fiber-optic cable over buried fiber cable made the telecommunications infrastructure more susceptible to hurricanes since aerial cable is exposed to the elements and more prone to potential damage. Second, FEMA officials noted that the utility poles supporting that aerial cable tended to be overloaded and not properly maintained. Thus, utility poles and the aerial fiber-optic cable supported by them were more susceptible to damage from high winds and from fallen debris than if cable had been predominantly underground and if poles had been properly maintained.

Third, maintaining the infrastructure in the mountainous central region of the island was even more challenging than in the more developed coastal zones. In addition to the preponderance of aerial cable, the lack of robust maintenance and the difficult geography, another major shortcoming for Puerto Rico's telecommunications infrastructure was its strong reliance on an aging electrical grid. One of the main wireless carriers described the dire situation of the energy sector prior to the hurricanes as follows:

4 Notice that this implies that 80% of Puerto Rico households used cellular devices exclusively.

5 A PSAP is a key component of the 911 system. "A primary PSAP is defined as a PSAP to which 911 calls are routed directly from the 911 Control Office, such as a selective router or 911 tandem. A secondary PSAP is defined as a PSAP to which 911 calls are transferred from a primary PSAP" (FCC, 2020).

> "The electric grid was outdated and extremely susceptible to hurricane damage, resulting in widespread and lengthy outages. The majority of the electric grid was composed of above-ground electric utility poles, which were brought down by sustained high winds or fallen trees. As a result, the communications infrastructure was also severely affected by the storm because the majority of AT&T's fiber was riding on electrical utility poles. In many areas, the fiber backhaul was simply gone." (*Reply Comments of AT&T*, 2018)

Another wireless carrier noted that power plants in Puerto Rico were on average 44 years old whereas the industry average is of 18 years (*Comments of T-Mobile USA, Inc.*, 2018).

An Emergency Operations Center (EOC) is a central location for the command, control and coordination of the emergency response in the aftermath of a disaster. There was only one EOC in Puerto Rico, co-located with PREMA headquarters south of San Juan. Puerto Rico did not have an alternate EOC that could function as a back-up for emergency management and coordination and executive decisions in case the primary EOC became inoperable.

The final shortcoming for the telecommunications sector prior to the hurricanes' landfall was not exclusive to this sector; that is, Puerto Rico's economic health was severely strained:

> "Before the hurricanes, Puerto Rico had over $74 billion in debt … an economy that had contracted nearly 15% over the last decade, and a nearly 50% poverty rate. In addition, Puerto Rico's structural budget deficits were projected to average 50% of recurring revenues.
>
> Puerto Rico is faced with a unique set of circumstances—the largest public entity restructuring in the history of the U.S. ..." (*Examining Challenges*, 2017)

Immediate Response and Initial Restoration Efforts

Immediate steps were taken by Federal Emergency Management Agency / Emergency Support Function #2 – Communications Annex (FEMA/ESF-2) and the U.S. Army Corps of Engineers (USACE) following Hurricane Maria to restore public safety communications. USACE provided a generator to the primary PSAP and fueled it weekly, which allowed this PSAP to stay operational despite the limited ability to relay emergency calls caused by the failure of the commercial wireline infrastructure. FEMA/ESF-2 deployed tactical communications equipment—including Very Small Aperture Terminals (VSATs), radios, satellite phones, and Mobile Satellite Terminals (MSATs)—to GPR offices, police district headquarters, fire district offices, and EMS offices (FEMA 2017). Commercial carriers took steps

such as using cells on light trucks (COLTs), cells on wheels (COWs), and portable generators to provide cellular connectivity. They also used drones ("flying cell on wings") and network balloons to temporarily provide data, voice, and text messaging services. Moreover, four wireless carriers provided roaming at no extra cost to their subscribers to maximize the number of people who could have access to service with the coverage that was available (*Comments of CTIA*, 2018).

By April 2018, the FEMA Communications/IT sector team had finished a plan to prepare Puerto Rico for the upcoming hurricane season. The plan consisted of rapid actions to allow for continuity of communications for GPR (including municipalities), hospitals, fire, police, and emergency medical services (EMS), in the event of another disaster. As of July 2018, FEMA had installed LMR base station radios and provided G2 and Iridium satellite phones to the GPR, as well as provided hundreds of hand-held radios. Moreover, more than ninety MSATs had been installed in the two PSAPs, five EMS offices, twelve Puerto Rico Fire Department (PRFD) offices, nine Puerto Rico Police Department (PRPD) offices, and each one of the PREMA offices located in the twelve Puerto Rico emergency zones (FEMA, 2018). By October 2018, the PRPD system and microwave network had been 70% restored to their pre-Maria status, and the PREMA and the EMS systems and network had been restored to over 85% of their pre-Maria status.[6]

Commercial carriers pursued an aggressive effort to restore their networks: by March 2018, only 4.3 percent of cellular sites in Puerto Rico remained out of service (FCC 2018), and by June of that year, 99.8 percent of cellular sites (2653 of 2659) were operational.[7] However, most of the cellular sites needed to be powered by fuel-based generators for many months due to the prolonged failure of the electrical grid. As of April 2018, approximately 30 percent of the sites belonging to a major commercial carrier were still using generators.[8]

In spite of the immediate response and the initial restoration efforts, infrastructure that is critical for telecommunications, such as aerial fiber-optic cable, remains vulnerable to another disaster of Hurricane Maria's magnitude. The widespread damage caused by the 2017 hurricanes emphasizes the importance of having survivable technologies and systems in place that could provide a resilient telecommunications infrastructure.

Moreover, recovery efforts in the telecommunications sector will require upgrading systems, equipment and networks and bringing many of them up to

6 Personal communication between the authors and a senior official of the Puerto Rico Department of Public Safety (PR DPS). October 19, 2018.

7 Per www.status.pr, an official website of the GPR. This website stated that the last update on the status of Puerto Rico's cellular sites was on June 5, 2018. Accessed October 16, 2018. This website is no longer available.

8 Personal communication between the authors and a representative of that commercial carrier. April 10, 2018.

federal standards, leveraging new technology, improving maintenance procedures, and maintaining and nurturing human capital in this sector. These challenges also present the opportunity to expand broadband Internet access throughout the island and to make use of information technology (IT) for the benefit of Puerto Rico residents and to spur economic growth. In order to address these challenges, the Homeland Security Operational Analysis Center (HSOAC) prepared a plan for the recovery of the telecommunications sector in Puerto Rico, which is outlined in the following section.

Recovery Plan for the Telecommunications Sector of Puerto Rico

The recovery plan developed for this sector by the HSOAC consisted of 33 courses of action that were generated through the collaborative, joint efforts of many stakeholders, including federal agencies, GPR agencies, and Puerto Rico's commercial telecommunications providers. The HSOAC team also received feedback from municipalities and civil society partners.[9] The FEMA Communications/IT sector lead in Puerto Rico held leadership meetings twice a week for several months and oversaw the work by FEMA's Communications/IT Solutions-based team (SBT), a group of subject matter experts from federal agencies. The SBT provided valuable discussions as well as one of the main sources for the recovery plan developed by the Homeland Security Operational Analysis Center. We also sought insights from multiple GPR agencies, including the Puerto Rico Telecommunications Bureau, the Puerto Rico Department of Public Safety (PR DPS), the Chief Information Officer (CIO), and the Chief Innovation Officer (CINO).

One of the authors was deployed to Puerto Rico for six months, attended most of the leadership meetings, and personally interviewed numerous stakeholders on the island. Other authors visited the island on more than one occasion and participated in meetings and interviews. Moreover, we held discussions with federal regulators at the Federal Communications Commission (FCC), with Puerto Rico telecommunications providers, and with wireless infrastructure and cellular carrier associations. Finally, we partnered with People Centered Internet (PCI) to develop COAs related to information technology.

Detailed descriptions of each one of the 33 COAs, including technical approach, needs addressed, estimated costs, benefits, potential shortcomings, candidate sources of funding, potential implementers, and precursors are provided in *Recovery Plan for the Communications and Information Technology Sector After Hurricanes Irma and Maria: Laying the Foundation for the Digital Transformation of Puerto Rico* (Cordova et al., 2020). Technical inter-relationships between COAs are explained in Chapters 4, 5, and 6 of that reference. We will provide a summary

9 We received this feedback through the work of the HSOAC teams responsible for developing courses of action (COAs) in the Community Planning and Capacity Building (CPCB) Sector and in the Municipalities Sector.

of these COAs in this article. They are presented in three groups, plus one overarching COA.[10]

Emergency Services and Continuity of Government

Eleven COAs of the first group aim at building resilient public telecommunications for emergency services and continuity of government. *CIT_03 Upgrade and Enhance 911 Service* will ensure that 911 centers will have state-of-the art equipment. This COA also recommends consolidating the functions of 911 centers with first responder dispatch in the same facility to reduce the vulnerability of emergency service response to a future disaster. Currently, a 911 operator must use telephone lines to call police, ambulance, or fire dispatch operators, who then use a separate system (typically radios and microwave networks) to dispatch first responders to the location of the initial caller.

Three more COAs pertain to disaster management command and control centers such as an Emergency Operations Center (EOC). First, *CIT_06 Upgrade and Modernize Puerto Rico's EOC* will ensure modernization of the Puerto Rico EOC that is collocated with PREMA headquarters. *CIT_07 Alternate EOC* will establish a back-up location for emergency management activities should the primary EOC in San Juan become inoperable. This COA also envisions establishing a 911 center in the alternate EOC to serve as a backup to the 911 centers in San Juan. *CIT_08 Mobile Emergency Operations Center* calls for the purchase and use of a National Incident Management System (NIMS) Type 2 or a similar vehicle. NIMS vehicles were brought by FEMA to the island after the hurricanes. These COAs are not independent of each other, and during implementation they should be addressed together.

CIT_05 Implementing Backup Power Systems will address the need for providing the public safety and government telecommunications networks with alternate power sources in the event of damage or destruction to the electrical grid. It will implement back up power for public tower sites; hospitals; police, fire, and EMS stations; municipal city halls; and government centers.

Two COAs address communications systems to service Puerto Rican communities. First, *CIT_09 Auxiliary Communications (AUXCOMM)* leverages volunteer radio groups and organizations that already exist in Puerto Rico and that were able to provide critical communications in support of hospitals and municipalities in the aftermath of Hurricane Maria. Second, *CIT_04 Rural Area Task Force* proposes establishing a group of experts to assess what are the best information systems and communications networks to service the needs of disadvantaged people during and after a disaster. These are people typically situated in rural or

10 During a call with a senior official of the Government of Puerto Rico, on February 19, 2021, we learned that the majority of these COAs have not been yet implemented, but are still under active consideration.

disconnected areas of Puerto Rico, especially those who are isolated, have limited mobility, or are elderly, and their caregivers.

Three COAs address additional methods to enable emergency communications and functions in the aftermath of a disaster. First, *CIT_11 Procure a Mobile Emergency Communications Capability* envisions the procurement of deployable assets that can be safely cached in Puerto Rico and quickly installed throughout the island to restore voice and data communications for disaster response, emergency services and government activities. Second, *CIT_20 Continuity of Business at PRIDCO Sites* will provide critical communication systems required to maintain key business activities at Puerto Rico Industrial Development Company (PRIDCO) sites when primary communications methods are degraded or unavailable. Third, *CIT_23 Data Collection and Standardization for Disaster Preparedness* will provide for the continued maintenance and expansion of a web site launched by the GPR to update the media, public, and first responders about conditions across the island.

The final COA of this group, *CIT_01 Land Mobile Radio (LMR) System,* consists of preparing a plan for Puerto Rico's public telecommunications infrastructure that considers several alternatives and their expected timelines. This COA also addresses the important need for maintaining a workforce on the island that can ensure the readiness of this infrastructure, as well as the need for workforce development in the form of four-year Electrical Engineering Bachelor of Science degrees.

Private Sector Partnerships

The next group of eight COAs proposes partnering with the private sector for a robust private telecommunications infrastructure and for broadband Internet deployment. *CIT_21, Government-Owned Fiber-Optic Conduits to Reduce Aerial Fiber-Optic Cable and Incentivize Expansion of Broadband Infrastructure,* was designed to provide a strong incentive to the private carriers to deploy fiber optic cable in buried conduit instead of mounting the cable on poles. This COA proposes that the GPR perform the required trenching and bury empty conduit. These two steps are the most expensive part of burying fiber optic cable. GPR would own the conduit, but the carriers would install in that conduit fiber-optic cable that they will own. GPR may ask the carriers to pay a reasonable fee for using the conduit network or create some form of cost-sharing mechanism. *CIT_12, Site Structural Analysis for Telecommunications Towers,* is important because towers used for emergency services are part of the critical infrastructure of Puerto Rico and are susceptible to damage by severe weather, such as hurricanes.

Four COAs address how the private sector can spur the deployment of broadband Internet service. Broadband access can be linked to many well-documented benefits, such as a significant impact on economic growth, wages, medical

care, and education, among others. The first two COAs of this sub-group (*CIT_25* and *CIT_13*) address how improvements in governance could foster broadband expansion in Puerto Rico. First, the GPR could work with a blue-ribbon panel of experts to evaluate and implement alternative methods to deploy broadband Internet service throughout the island (*CIT_25*). Second, the government could consolidate and streamline the permitting and rights of way processes for towers and the deployment of fiber optic cable by telecommunications providers (*CIT_13*). Two more COAs in this sub-group (*CIT_22* and *CIT_19*) address how Puerto Rico could benefit from additional federal funding for two existing programs. The first is the E-Rate program, with funding supplied by the FCC, which supports telecommunications services (including broadband Internet services) for qualified schools and libraries (*CIT_22*). The second program is currently funded by the Telecommunications Bureau in Puerto Rico, which supports 58 municipal wi-fi hotspots throughout the island (*CIT_19*).

An important ingredient of the recovery plan was a novel public-private partnership that integrates several of these COAs (Cordova, 2021). Puerto Rico's telecommunications network relies heavily on the availability of an undersea network infrastructure for connectivity to the mainland U.S. and other regions of the world. Thus, the last two COAs of this group pertain to improvements to the island's undersea cable infrastructure. *CIT_10, Transoceanic Submarine Cable,* will introduce new, very high bandwidth undersea cable(s) to Puerto Rico, situated away from San Juan, including one landing point for the mid-term, followed by additional ones in the long term to increase capacity and route options for telecommunications. Complementary to the inter-region submarine cable(s) of that first COA, the focus of *CIT_15, Undersea Cable Ring,* is to strengthen Puerto Rico's ability to communicate within and around the island over high speed and high-capacity links through a network infrastructure for a communications ring system.

Information Technology for Critical Infrastructure

The third and last group of recommendations addresses information technology (IT) for critical infrastructure and for the digital transformation of Puerto Rico. The first two COAs are critical for the computing infrastructure of the island. *CIT_17, Puerto Rico Data Center,* addresses the need for a state-of-art, standards-compliant data center in Puerto Rico. *CIT_02, Puerto Rico Geographic Information Systems (GIS) Resource and Data Platform,* will build a comprehensive, real-time, and readily available information system that provides geolocated information to governmental public safety officials, emergency response teams, and community planning agencies. *CIT_18, Data Storage and Data Exchange Standards for Critical Infrastructure,* will establish data storage and data exchange standards for critical infrastructure.

During the course of this work, Puerto Rico was considering consolidating its 130 government agencies into approximately thirty; two more COAs address

methods to make government information systems and functions more effective during this consolidation. *CIT_14, Consolidated Government Information Systems,* will establish and implement an open, modular, standards-based platform for information systems, and will consolidate government systems. *CIT_33, Government Digital Process Reform,* will work together with *CIT_14* but will emphasize organizational culture and process change. The action for consolidating information systems and addressing corresponding technical challenges (*CIT_14*) will complement the effort to revise governmental methods and policies to drive how systems can or should be utilized with the intent of improving government services provided to citizens (*CIT_33*).

The next eight COAs in this group are about the digital transformation of the island, with emphasis on digital transformation of the government. *CIT_16* consists of two steps. The first one is to increase the human capacity of Puerto Rico Innovation and Technology Services (PRITS) by adding expertise and staffing; experts on data science, data architecture, IT architecture, and cybersecurity will be added to PRITS, as needed. The second step consists of the creation of the roadmap for the digital transformation of Puerto Rico.

Three COAs address citizen-oriented digital initiatives. *CIT_26* will establish wi-fi hotspots in public housing and a "Digital Stewards" program to be modeled after similar initiatives in Detroit, Michigan and Red Hook, New York. This program intends to improve digital connectivity options in public housing and provide valuable digital skills for people in those communities. *CIT_27* prescribes a study of existing models for "digital identities"; the creation of a secure digital identity will facilitate digital transactions and reduce transaction costs, while decreasing the potential for fraud and identity theft. *CIT_32* seeks to expand the scope of PRITS to include a focus on citizen-centered services and prioritize a "one-stop-shop" experience for accessing government services and information in an easy-to-use fashion.

CIT_29 addresses improvements in the health sector and has two complementary objectives. First, it seeks to provide a robust, resilient, multi-modal "mesh" communications network to clinics to complement connectivity that is available through the telecommunications infrastructure or to provide redundancy when such infrastructure is damaged. Second, it uses the increased connectivity and IT to ensure real-time access to clinical data—including mobile and telehealth.

CIT_28 will create a public-private initiative to provide digital skills training, entrepreneurship programs, and access to new digital technologies through a network of innovation hubs and entrepreneur centers, training partnerships with schools, and outreach via mobile laboratories to rural and underserved areas. The last two COAs of this group take advantage of IT to improve the resilience of the island. *CIT_30* will create a Resiliency Innovation Network (RIN) across Puerto Rico to build on the existing Puerto Rico Science, Technology, and Research Trust

(PRSTRT) and university facilities to teach, test, and refine existing resiliency products and services, and to develop new ones to enhance capability and stimulate new commercial ventures. *CIT_31, Resilience/e-Construction Learning Lab,* will execute a 1-year pilot project to digitize assessment, permitting, and reporting processes in one Puerto Rican municipality and present findings to inform the feasibility and cost-benefit analysis for an island-wide e-Permitting and e-Construction ecosystem.

Finally, one overarching COA, *CIT_24,* will establish a new Communications Steering Committee through Executive Order by the Governor. The main task for this committee is to provide strategic guidance, policy, direction, and standards related to Puerto Rico telecommunications networks. The committee will also ensure proper planning and collaboration to effectively and efficiently recover and to maintain the telecommunications infrastructure, as well as mitigate interoperability and duplication of effort issues

Conclusion

The 2017 hurricane season resulted in unprecedented and widespread destruction of Puerto Rico's public safety, wireline, wireless and cable networks, infrastructure and systems. The damage severely affected emergency response, increased the risk to public safety, and had a serious impact on Puerto Rico's economy. The hurricanes also limited the ability of the government to continue functioning and had a severe and enduring impact on the well-being of Puerto Rico residents. In particular, it left many residents without access to critical emergency services at a time when they needed them the most. In addition to hurricanes, Puerto Rico is prone to other natural disasters, as demonstrated by the many earthquakes experienced by the island in December 2019 and January 2020; the three strongest had magnitudes of 5.8, 6.4 and 5.9 on the Richter scale.

Besides restoring their networks, by the end of 2020, the Puerto Rico private telecommunication carriers had installed 1,400 miles of buried fiber-optic cable, which augments the 2300 miles of buried cable existing prior to Hurricane Maria.[11] Moreover, the backhaul fiber ring that ran along the Puerto Rico coast encircling the island prior to the hurricanes has been augmented by two additional backhaul fiber rings. On October 2020, the GPR announced a new initiative called the Broadband Infrastructure Fund "to support [broadband] expansion efforts in unserved and underserved areas through grants that fund a portion of the deployment costs in these communities" (Puerto Rico Fiscal Agency and Financial Advisory Authority, 2020). Furthermore, the U.S. Federal Communications Commission, via its Uniendo a Puerto Rico fund, authorized $233.9 M to three telecommunication carriers serving the island. These funds included approximately

11 Personal communication between the authors and a senior official of the Government of Puerto Rico. 19 February 2021.

$59.5 M targeted for 5G deployment, which is the first universal service funding awarded in the U.S. that is aimed specifically at 5G deployment (Federal Communications Commission, 2020, December 9).

Despite the great strides toward repair and restoration of the damaged infrastructure (in particular, the private telecommunications infrastructure), the telecommunications sector in Puerto Rico remains vulnerable to major natural disasters (e.g., hurricanes, earthquakes, and tsunamis) and human-originated crises (e.g., terrorist attacks).

Concerning funding for disaster relief and reconstruction from the U.S. federal government, delays and severe restrictions on the use of these funds were imposed by the prior administration (*New York Times*, 2020), However, the current administration is following a different policy vis-à-vis federal funding of Puerto Rico recovery: it plans to release $1.3 billion in delayed aid and will remove prior restrictions on an additional $4.9 billion in relief funds. "The funds are part of a $20 billion package that Congress gave to the Department of Housing and Urban Development to help Puerto Rico after Hurricane Maria" (Democracy Now, 2021). It is not clear at this time whether any of these funds will be used in the telecommunications sector.

In this paper, we have summarized the 33 courses of action developed for the recovery plan of the telecommunications sector in Puerto Rico. Substantial investment is still required to achieve a resilient and robust telecommunications sector in Puerto Rico. The estimated cost for the 33 COAs was $3.2 billion. Although this dollar figure may seem high, it is a fraction of the overall cost of the recovery plan, which was $139 billion.

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Acronyms

COAs	Courses of Action
DSL	Digital Subscriber Line
EMS	Emergency Medical Services
EOC	Emergency o\Operations Center
ESF-2	Emergency Support Function #2 – Communications Annex
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
HSOAC	Homeland Security Operational Analysis Center
GPR	Government of Puerto Rico
ILEC	Incumbent Local Exchange Carrier
LMR	Land Mobile Radio
MSATs	Mobile Satellite Terminals
PRDPS	Puerto Rico Department of Public Safety
PREMA	Puerto Rico Emergency management Agency
PREPA	Puerto Rico Electric Power Authority
PRFD	Puerto Rico Fire Department
PRPD	Puerto Rico Police Department
PRSTRT	Puerto Rico Science, Technology, and Research Trust
PRTB	Puerto Rico Telecommunications Bureau
PSAP	Public Safety Answering Point
PSTN	Public Switched Telephone Network
SBT	Solutions-based Team
USACE	United States Army Corps of Engineers

Author Capsule Bios

Amado Cordova is a senior policy researcher at the RAND Corporation, with research aimed at answering policy questions in homeland security and national defense. He has been principal investigator in various RAND research units—Project Air Force (PAF), Arroyo Center, Homeland Security Operational Analysis Center (HSOAC), and RAND Health Care—and has led projects on subjects such on acquisition, strategic planning, identification of innovative technologies and technology roadmaps. His team led the Communications and Information Technology (Comms/IT) team for the HSOAC Puerto Rico recovery project discussed herein and produced the recovery plan for the island's Comms/IT sector. Other recent projects include PAF, for which his team assessed what improvements in timeliness, reliability, and maintainability can be achieved in the Minuteman ICBM by implementing new navigation and guidance technologies. For the Arroyo Center, he worked on investigating the impacts of adopting common architectures within the Future Vertical Lift (FVL) program. He was member of the modeling team of COMPARE (Comprehensive Assessment of Reform Efforts) to analyze the impact of the Affordable Care Act. Prior to RAND he was Chief Technology Officer of Copley Networks, California. Before that, at Litton Industries, he and his team designed and developed the world-most-robust fiber-optic gyroscopes for military and other applications. For his contributions he received Litton's C. Thornton Advanced Technology Award. He earned a Ph.D. in electrical engineering from Stanford University, a Diplome d'Ingenieur from SUPELEC (France) and a B.S. in physics from UAM (Mexico). He is author or coauthor of 23 U.S. patents and of 48 publications (RAND reports and journal articles).

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