A Framework for Healthcare Resilience During Widespread Electrical Power Loss

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Abstract

Healthcare delivery systems are vulnerable to a prolonged loss of electric power, particularly an extended regional or multi-region breakdown in the electric grid. This is attributable to the reliance of acute care and ambulatory facilities on continuous electric supply for both life-saving and vital facility support functions. We describe how a framework for disaster resilience can be applied to improve healthcare system adaptability to such scenarios. Our recommendations emphasize important preparedness efforts necessary to maintain—as best as possible—healthcare services during a period of extended regional of multi-region electrical power loss.

Specifically, we call for the development and activation of energy resilient disaster resource hospitals, the need for enhanced healthcare coalition (HCC), Medical Reserve Corps, and national disaster medical system involvement during high-impact electric outage conditions, the necessity for a centralized federal coordination function, and public engagement to facilitate a culture of resilience to health disasters, including the extended loss of power. In order to increase preparedness, we advocate the development and implementation of pilot projects intended to enhance health sector resilience to power grid failure.

Keywords: disaster resilience, healthcare resilience, healthcare coalition, power outage, hospital energy supply, energy resilience

Introduction

In 2018, the Johns Hopkins Center for Health Security released a report titled *A Framework for Healthcare Disaster Resilience* (the report) (Toner et al. n.d.). Funded by the Robert Wood Johnson Foundation (RWJ), the report reported two years

 doi: 10.18278/jcip.1.1.3

Table 1: Disaster Types, Characteristics Burdens and Scopes

Disaster Type	Characteristics	Burden on the Healthcare System	Scope of Response	Examples
Relatively small mass injury/ illness event	Infrastructure remains intact - Most response resources exist in the local area - Most normal healthcare capacity remains intact (isolated damage possible: e.g., Joplin tornado) - Vulnerable populations at somewhat greater risk for some events (e.g., infectious disease outbreaks, shootings, tornados), but not all	Transient surge, typically limited to hospitals	Local HCCs: - Local hospitals - Public health - EMS - Emergency management agency	- Bus crash - Tornado - Multiple shooting or smaller mass shooting - Local infectious disease outbreak/ epidemic
Large-scale natural disasters	- Infrastructure damaged to some extent - Healthcare facilities are degraded - Affected population is displaced from normal site of healthcare - Vulnerable populations are at the greatest risk - Most patients are not direct casualties; patients instead are displaced from their normal sources of healthcare	- Many parts of the system degraded, some for a prolonged period of time - Transient surge in emergency department patient volume; could be large - Prolonged surge in many parts of the healthcare system that remain functioning	One or more HCCs with outside mutual aid, federal support, and strong community and health sector resilience	- Hurricanes (e.g., Sandy, Katrina) - Moderate earthquakes (e.g., Napa 2014) - Large-scale flooding (e.g., 1993 Mississippi and Missouri River floods)
Complex mass casualty events	- Infrastructure wholly or largely intact—bombings or fires could affect some infrastructure - Normal healthcare capacity is intact - Specialty care and/or specialized training required to treat a large number of patients - Vulnerable populations are not at substantially greater risk	High burden of trauma, critical care, specialty care on multiple healthcare facilities - Transient and prolonged surge could overwhelm surge capacity at individual facilities, but the broader local or regional healthcare system capacity is largely sufficient—some specialty care capacity may be placed under higher burden for some events (e.g., large-scale burn events)	Multiple large specialty hospitals with robust capabilities, plus one or more HCCs	- Large-scale shooting (e.g., Las Vegas 2017) - Bombing with many victims (e.g., Oklahoma City 1995) - Mass casualty burn event - Large-scale decontamination of patients (e.g., radiological accident, chemical spill, white powder incident) - Chemical, radiological, or limited scale biological terrorism (e.g., 2001 anthrax attacks)

Catastrophic health event	- Infrastructure may be severely damaged in some events - Normal healthcare system may be degraded, severely in some events - Many complex casualties occurring simultaneously - Affected area and population will vary by event, but they likely cover a large geographic area - Vulnerable populations are at elevated risk	- Severely increased burden on local and regional health sectors may overwhelm surge capacity, even if the healthcare infrastructure remains intact - National coordination and augmentation will likely be required for the response	National-level response, requiring coordination and resources from outside the affected area	- Nuclear weapon detonation - Large-scale bioterrorism - Severe pandemic - Massive earthquake (e.g., Northridge, CA, 1994)

of policy research on how well the US health sector was prepared for a variety of disasters. That effort, in turn, was informed by prior research into healthcare and public health preparedness; specifically the impact of Hurricane Sandy and Ebola virus disease on affected cities in the United States (Meyer et al. 2018; Sell et al. 2018; Toner et al. 2017). The report described a framework for an improved disaster healthcare system and made recommendations for how the existing US healthcare preparedness and response system could be strengthened.[1]

In this article, we expand the framework for a critical issue that was not explicitly considered: the healthcare impacts of a prolonged regional or multi-region electrical power outage. The extended loss of power represents a substantial risk to healthcare provision, whether caused by natural disasters, cyberattacks on the electric grid, breakdowns in older legacy power generation and electric distribution systems, physical attacks, or electrical system vulnerabilities to large solar storms or an electromagnetic pulse (EMP). The findings and recommendations provided herein are intended to improve healthcare preparedness for such events.

About the Framework

Our RWJ report contained a framework to build a more effective disaster health system in the United States. It described four types of disasters: 1) relatively small-scale mass injury/illness events, 2) large-scale natural disasters, 3) complex mass casualty events, and 4) catastrophic health events. The attributes of each disaster type are shown in Table 1.

Depending on causation and severity, a long-term regional or national power outage would have devastating healthcare consequences. The impact of such an event could transcend the categories of large-scale natural disasters and catastrophic health events and complex mass casualty events. An extended power

1 One of the authors of this current paper (ET) was the Principle Investigator of that project.

loss would degrade the capabilities of both healthcare facilities and other response organizations. Based on the interconnectedness of critical infrastructures—e.g., electric power, communications, water supply, transportation and the pharmaceutical and food supply chains—hospitals, in particular, could face enormous operating challenges.

Large-Scale Power Outages

As noted, large-scale power outages were not explicitly included in our initial report. However, the framework is applicable to critical evaluation of the profound healthcare challenges that an extended outage event would cause at the regional or multi-region scale. Depending on its duration, the impacts on healthcare delivery could exceed those of large-scale natural disasters, complex mass casualty events, and catastrophic health events.

An extended regional or multi-region power outage can be precipitated by multiple factors, some internal to the power grid and connected infrastructures and some due to a host of external events. The US electric grid is extraordinarily complex, subdivided into thousands of interrelated components. Seventy-two percent of utility customers, including hospitals, receive electricity from investor-owned utilities that issue stock owned by shareholders. In addition, there are electric cooperatives and approximately 2,000 publicly owned utilities (US Energy Information Administration, 2019). Major components of the US electric grid are comprised of older legacy systems.

Most major outages are attributable to damage to large transmission lines or electric substations, and these have greatly increased in recent years (Kenward and Raja 2014). As noted by Lewis (2015), "The frequency and size of power outages have been rising exponentially since deregulation in 1992. This increase is traced to a number of factors, including, but not limited to, underinvestment in transmission and distribution, deregulation of utilities resulting in loss of control" (236). As an example of both the interconnected nature of power systems and potential extent of regional power loss, a two-week outage, commonly referred to as the Northeast Blackout of August 2003, was triggered by foliage in Ohio that brushed against power lines. This set off a cascade of power failures stretching from southeastern Canada through eight northeastern US states that affected approximately 50 million people (Minkel 2008, 13).

Natural disasters are one of the most likely causes of severe power outages. Severe weather incidents, such as winter storms, hurricanes, or tornadoes, can significantly damage the power grid and affect multiple regions of the country. Aside from healthcare facility challenges related to power loss, these incidents can have independent service provision impacts, such as dramatically increased emergency response times. Another example of natural disasters impacting electric service are wildfires that may damage power utility infrastructure as well as attempts by utility companies to prevent them though preemptive power shutdowns in hot, dry weather.

Manmade threats also have the capability to cause large-scale, potentially catastrophic power outages. Cyberattacks on electric utility companies are significant and rising. A recent study of 1,726 utility company professionals revealed that 56 percent of respondents had reported at least one shutdown or operational data loss event per year, and 25 percent of respondents were impacted by mega attacks with nation-state levels of expertise (Ponemon Institute and Siemens n.d.). The risk that cyberattacks pose to electric power system operational technology is a problem that will only grow more significant as the capabilities of malicious actors improve. Potentially more disruptive power outages could result from an EMP that could cripple electric power systems and an array of electronics at the community level for long periods of time. These threats were most recently outlined in a Presidential *Executive Order on Coordinating National Resilience to Electromagnetic Pulses* (The White House 2019).

Healthcare System Impacts of Extended Power Loss

The healthcare and public health sector, one of sixteen national infrastructure sectors, is highly susceptible to impairment from the loss of electricity, which typically occurs in a context of community-wide power failure. Modern day healthcare facilities are reliant on electricity in order to operate advanced electronic equipment, conduct patient record keeping, facilitate communications, maintain adequate water supply, and conduct numerous subsidiary functions, such as laboratory operation, pharmaceutical refrigeration, and air handling systems (Klinger and Landeg 2014). A Department of Homeland Security (DHS, 2014) assessment notes a 67-99 percent degradation of core hospital functions after five minutes without backup electricity sources, after ten minutes without information technology, and after two hours without water and wastewater. During Hurricane Katrina, hospitals without electricity were unable to deliver the appropriate standard of care for ICU patients without the ability to use mechanical ventilators, bedside monitors, and dialysis machines (Franco et al. 2006). Hurricanes, especially those in which back up emergency power failed (e.g., Katrina, Sandy, and Maria), illustrate the devasting impact of power grid failure on hospitals (Adalja et al. 2014; Alcorn 2017; Franco et al. 2006).

Across a range of healthcare and healthcare support systems, widespread electrical power outages effectively block many basic processes and practices essential to the practice of modern medicine. These include access to electronic medical records, medication ordering, and measuring vital signs—blood pressure cuffs, thermometers, and scales—all of which are mostly electronic. Although non-electronic technologies were used in the past, these alternatives are often no longer readily available and personnel may not be trained in their use. The cascading impacts of multiple facilities affected by long-term power outage may, over a long-term power outage, force large geographic areas into a "crisis standards of care" environment, potentially for a prolonged period.

Widespread electrical power loss also affects healthcare support systems and health sector components beyond hospitals (Adalja et al. 2014). For example, home healthcare, both formal and informal, utilize medical devices that are dependent on electricity. These include, but are not limited to, home ventilators, continuous positive airway pressure (CPAP) machines, and left ventricular assist devices (LVADs). Additionally, critical outpatient facilities, such as dialysis and infusion centers, are dependent on continuous supplies of electricity. Long-term care facilities manage fragile populations with vulnerabilities that may be particularly susceptible to increased morbidity and mortality during extended electrical power loss. These vulnerabilities may be exacerbated when combined with extreme weather such as unusually cold or hot temperatures. At the community level, a lack of electric power directly impacts the food and pharmacy supply chains, telecommunications, water supply, wastewater treatment, and other population health requirements.

All hospitals and some other healthcare facilities have emergency electrical generators; however, these may experience serious limitations as the length of an outage increases. Emergency generator reliability can decrease with continuous use. Although the Joint Commission, Det Nosrke Veritas (DNV), other accrediting bodies, and the Centers for Medicare and Medicaid Services (CMS) require that healthcare facilities evaluate their ability to maintain essential operations for ninety-six hours without external assistance, the requirement is for an assessment rather than actual long-term backup power availability. Because emergency power testing is disruptive to normal operations, some facilities may avoid prolonged or frequent testing beyond the minimum required by regulation. Generators sometimes fail when challenged with full loads for more than a short time (Winters 2014). After fuel depletion, additional fuel supplies (typically diesel) are needed and may not be available in the face of a wide-area power outage. Reliable just-in-time resupply may not be possible. Moreover, generators typically only supply electricity to selected critical functions in a hospital, and unsupplied functions may become urgent over time. Depending on facility location and other circumstances, challenges associated with the loss of water pumps or heating, ventilation, and air conditioning (HVAC) may become insurmountable.

In the past, many hospital emergency generators were installed on the ground floor or basement and thus subject to flooding. Following the catastrophic floods caused by Hurricane Katrina, some hospitals relocated generators to higher floors. However, moving fuel supplies to higher floors can be hazardous if tanks leak. A solution is to pump fuel from ground level to the generator, but this requires submersible fuel pumps and electrical systems. The failure of the electrical supply to a flooded fuel pump caused the loss of emergency power in part of Bellevue Hospital in New York following Hurricane Sandy (Powell, Hanfling, and Gostin 2012).

A relatively new approach is to provide emergency power generation through microgrids integral to or involving major hospitals. Such microgrids involve local power sources (e.g., distributed generators, fuel cells, renewables, thermal sources, etc.) that can operate on a continuous basis and can supply most or all of a hospital's power needs. They are integrated with but can function independently from the overall electrical grid. They can sell excess power to the grid, assist electricity suppliers during peak periods and, importantly, operate in island mode, disconnecting from the grid in the event of its failure. During Hurricane Sandy, for example, the Princeton University microgrid automatically entered island mode upon the shutdown of its local New Jersey utility. Throughout the disaster, power was provided to 150 university buildings including healthcare delivery sites (Kelly 2014).

Applying the Healthcare Resilience Framework

Five critical recommendations presented in our original report are adapted here for cases of extended, region-wide extended power loss:

1. *Continue robust support for the Hospital Preparedness Program (HPP), focused on growing and maturing Healthcare Coalitions (HCCs).*

   The HPP program is administered by the Office of the Assistant Secretary for Preparedness and Response (ASPR) at the Department of Health and Human Services (HHS). This program has been foundational in marshaling healthcare assets for mutual support during emergency response and recovery. HCCs play a vital coordinating function among healthcare facilities in response to major emergencies as part of National Health Security Strategy Objective 1: "Prepare, Mobilize, and Coordinate a Whole-of-Government Approach" (US Assistant Secretary for Preparedness and Response n.d.). They typically comprise—at a minimum—local hospitals, public health agencies, emergency medical services and emergency management agencies. In many locations, other healthcare entities including nursing homes, home health agencies and outpatient clinics have joined HCCs. HCCs engage in collaborative planning, joint exercises, and, in some locations, joint stockpiling. In advance of an extended regional power outage, these organizations are situated to assume key roles in planning, training, and conducting exercises to enhance local healthcare survivability and effectiveness.

   HCCs are especially relevant given the regional nature of widespread power outages, the fact that HCCs operate across multiple jurisdictions, and that they can include otherwise competitive healthcare organizations. In a widespread, prolonged grid down event, HCCs could play critical roles in facilitating situational awareness on the cascading impacts of power failure and the resource needs of both individual healthcare facilities and the broader healthcare delivery system. This would include information about community conditions that affect the continuity of patient care.

HCCs could also upgrade the coordination and management of scarce resources in a "crisis standards of care" environment by facilitating critical supply and personnel sharing. This may include addressing the patient load for overwhelmed facilities and the coordination of medical surge and clinical care strategies across organizations. In addition, HCCs could enhance collaboration among healthcare facilities if food, water, and other critical support systems were impaired due to a protracted power outage. Importantly, when acute care and ambulatory systems cease operation in the aftermath of a prolonged power system failure, HCCs—in tandem with other organizations—can help stand up a modicum of healthcare services to the affected communities. These could take the form of medical shelters described in recommendation 2 (below).

However, in order to assume these responsibilities, planning beyond existing systems of cooperation and mutual support are required. To the extent that the geographic spread of power loss extends beyond the jurisdictions of relevant HCCs, cooperative and mutual support agreements should be proactively adjusted. Additional resources, beyond traditional funding levels of HCC would be needed to fully invest in building the joint capabilities described. We propose a pilot project in which one or more HCCs plan for an extended regional power outage and then test it through a series of tabletop exercises followed by limited functional exercises. Such a pilot could be funded by HPP in a competitive bidding process or by a healthcare philanthropy.

2. *Integrate local Medical Reserve Corps (MRC) and National Disaster Medical System (NDMS) units with their respective HCCs.*

Local MRCs provide teams of volunteer medical and public health professionals who bring additional skills and expertise to a response while NDMS units represent teams of physicians, registered nurses, dentists, paramedics, and other medical and support professionals that can be activated. Teams from the MRC, NDMS, American Red Cross, local health departments, and an array of community-based organizations could help organize and staff field shelters for medically vulnerable individuals. These facilities could be activated during a prolonged power outage for citizens who do not require the full resources of hospitals, and particularly after individual hospitals were forced to discontinue operation. In addition, HCCs could provide administrative oversight in mobilizing community physicians, nurse practitioners, the state guard and other relevant personnel to support field shelters capable of providing a limited amount of healthcare assistance.

3. *Initiate a new program designed to promote a Culture of Resilience at the local level.*

Strengthening resilience across the entire health sector is critical in the face of electric power loss. Resilient communities incentivize community organizations to: 1) enhance their own resilience to disasters, 2) support and encourage their community's resilience efforts; and 3) engage with local HCCs to maximize preparedness and resilience. While energy-resilient hospitals are necessary, a growing quantity of healthcare occurs outside hospital campuses, nearly all of which is dependent on electricity. Freestanding outpatient clinics, pharmacies, home health providers, medical suppliers, and other ambulatory facilities need to be committed to resilience—their own as well as surrounding communities. This involves individual organizational planning and backup procedures, but collaboration with other community partners, such as HCCs, is crucial.

It is doubtful that the general public understands the extent of healthcare system reliance on electric power and its vulnerability to severe power outages. Public perceptions and expectations are shaped by past disasters, and power-related infrastructure vulnerabilities have not been widely reported (Rojahn et al. 2019). We recommend that a public awareness campaign be organized to educate communities on preparedness actions at the personal, healthcare system, and government levels to improve resilience for the health impacts of a long-term, widespread power outage. It incorporates power grid vulnerabilities, the inadequacies of current back-up power systems, and healthcare delivery system dependence on uninterrupted power supply.

Vulnerable populations, requiring continued access to electricity-dependent services would be a key target population. Goals of such a campaign would include fostering greater resilience across the healthcare and public health sector and building public support for federal policy (DHS and Department of Energy), ensuring an electrical supply system that is less vulnerable than currently is the case. To be most effective, such a campaign should involve a coalition of philanthropies and non-governmental organizations working in partnership with federal, state, and local government.

4. *Create a network of Disaster Resource Hospitals (DRHs)*

   Power-resilient DRHs could prove essential during and following a prolonged power grid failure. A network of geographically distributed disaster centers of excellence could be created by rigorous standard setting, providing direct funding, and requiring accountability. These hospitals could become models for other hospitals through advanced practice innovation. ASPR has begun developing a new system for regional catastrophic disaster medical care built upon the HCC system to address healthcare preparedness challenges. However, further research is needed on 1) best practices for healthcare facilities and HCCs and 2) contingency and crisis standards of care if there is a partial or complete loss of power for an extended period. DRHs can be a resource for promulging best practices to other facilities or HCCs through education, training, and expert consultation.

   DRHs, all of which are expected to be large academic medical centers, are natural anchor facilities for microgrids that supply not only the hospital, but also other surrounding critical infrastructure, such as government buildings and even local military bases. In many cases, large academic hospitals are located in state capitals and other urban centers, and some large hospitals already have microgrids. We recommend that the federal government (e.g., DHS, Department of Energy National Renewable Energy Laboratory, Defense Advanced Research Projects Agency, etc.) consider funding a pilot project to explore the feasibility of establishing a network of hospital-based microgrids. These hospital-based microgrids could potentially supply other nearby health facilities, such as clinics, dialysis centers, laboratories, and pharmacies. Microgrid development should include safeguards to protect against an EMP.

   A growing list of initiatives provides practice wisdom in developing microgrid installations attentive to healthcare provision at the community scale. The Cleveland Foundation and the Cuyahoga County Executive are developing a major microgrid project in downtown Cleveland. It is tiered to provide non-interrupted power supply to hospitals and other customers requiring high quality electric service (Funk 2019). In San Antonio, Texas, the Air Force's Joint Base San Antonio, the largest Department of Defense installation, is spearheading a public-private effort to innovate military and civilian energy grids and develop optimized microgrid applications (Joint Base San Antonio News 2017). In California, microgrids are being explored to reduce the impact of public safety power shut offs and provide broader reliability to the power system (DeKunder 2019). In light of this, a strategic approach to hospital participation in microgrid solutions is warranted.

5. *Launch a new program within the office of ASPR that is focused on preparedness for catastrophic health events.*

   A program specifically focused on catastrophic health events would work collaboratively with HPP, NDMS, MRC, and other offices in ASPR. In addition, it would be integrated with relevant components of the Centers for Disease Control and Prevention, DHS, the Veterans Administration health system, and the Department of Defense health system. The rationale for this recommendation is that a prolonged regional or national electrical grid failure could have catastrophic impact on the provision of healthcare services, potentially putting tens of thousands of lives at risk. Focusing undivided attention on this and other catastrophic risks is an important federal preparedness role—one that might not be adequately addressed within the context of the competing demands of daily emergencies. Achieving an adequate preparedness level for catastrophic health events will require coordinated action from a range of stakeholders. A dedicated federal lead in ASPR would enable a policy framework and collaborative engagement across the governmental agencies, sectors, and systems necessary to achieve a higher level of resilience for these catastrophes.

Conclusions

A prolonged, widespread loss of electrical power has the potential to cause large-scale negative impacts on the healthcare delivery system. As the threat to power system failure grows, further work is required to safeguard the nation's capacity to deliver healthcare during such an event. Although not originally designed to encompass the contingency of pervasive electrical power loss, the *Framework for Healthcare Disaster Resilience* is directly applicable to this type of event. We emphasize the need to support enhanced healthcare coalition work to prepare for and respond to this threat, call for Medical Reserve Corps and national disaster medical system involvement during high-impact electric outage conditions, and highlight the importance of energy resilient disaster resource hospitals. We also emphasize the critical need for a centralized, dynamic federal coordination function for catastrophic health events and public engagement to facilitate a culture of resilience to health disasters, including the extended loss of power. To ensure a healthy and resilient nation, we also advocate the development and implementation of specific pilot projects intended to enhance health sector resilience to power grid failure.

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