Opportunities and Challenges for Resilient Hospital Incident Management: Case Study of a Hospital's Response to Hurricane Harvey

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Editor's Note: JCIP *has established an ongoing relationship with the* Resilience Week Symposium*, the preeminent research conference on transforming the resilience of critical infrastructure systems and communities. Organized by the country's national laboratories and other partners, the conference sponsors an annual student research competition. Each year,* JCIP *will determine whether to invite an expanded paper from winners of the conference's Best Presentation Award. This article marks the first such publication, submitted by a 2019 Resilience Week Student Competition winner.*

Abstract

Communities face unforeseen threats from natural and human-made disasters. As disasters grow more intense and critical infrastructure increases in complexity, resilience has emerged as an essential attribute of incident management systems. Despite concerted efforts to examine government organizations and their associated policies, understanding resilience traits exhibited by hospitals and healthcare systems during disasters is limited. We employ two fundamental viewpoints of safety to assess what went wrong (*Safety I*) and right (*Safety II*) during Hurricane Harvey in a large regional hospital. Through qualitative analysis of semi-structured interviews with hospital emergency management and operators, we examine both opportunities and challenges in six aspects of hospital incident management: organizational structure and functions; situational awareness; operating plans; human and physical resources; lessons learned from previous incidents; and leadership

and high-level decision making. The benefits of incorporating both the *Safety I* and *Safety II* frameworks in evaluating hospital incident response and the implications of this approach for disaster management policies are discussed.

Keywords: resilience, disaster response, hospital incident management, natural disaster, emergency management

Introduction

Over the years, communities have experienced increasing threats from natural and human-caused disasters, such as hurricanes, wildfires, volcanic eruptions, and industrial incidents. Between 1998 and 2017, global economic losses incurred by disasters amounted to nearly $3 trillion USD, of which the United States recorded the largest loss of $945 billion USD (United Nations Office for Disaster Risk Reduction 2018). Particularly troubling is the approximately twenty-fold increase in the frequency and intensity of such extreme events in the past two decades (Coronese et al. 2019).

Major challenges posed by these disasters include disruptions and damages to critical infrastructure functions that are highly coupled and complex. This results in increased difficulties with planning for and mitigating adverse impacts on social and environmental systems. For instance, the 9/11 World Trade Center (WTC) disaster clearly demonstrated the unprecedented challenges of a disaster to the critical functions of a society. Prior to the event, no public agencies or jurisdictions anticipated or prepared for such an act of terrorism in their emergency planning (Comfort and Kapucu 2006; Cruz, Burger, and Keim 2007). During the response to the incident, significant weaknesses were discovered from multiple interdependent critical infrastructure elements, such as electric power, water supply, transportation, and telecommunication (Kendra and Wachtendorf 2003; Mendonça 2007). When the twin towers collapsed, underground water pipelines were ruptured, flooding train tunnels and telecommunication cable vaults and exacerbating the problems being addressed (O'Rourke 2007).

In order to protect critical infrastructures from disasters, and thereby sustain public welfare and economic prosperity, there have been continuous efforts in the United States to provide a standardized incident management framework for all-hazard scenarios. The primary example of this is the National Incident Management System (NIMS), first launched in 2004 in the aftermath of the 9/11 WTC disaster (Perry 2003). NIMS requires all government agencies and jurisdictional organizations (e.g., firefighting, law enforcement, emergency medical service) to adopt the Incident Command System (ICS), a core protocol that guides organizational structure and operating processes in response to local emergencies to cat-

astrophic disasters regardless of their type and size (Federal Emergency Management Agency [FEMA] 2017).

The ICS has been advocated by policymakers and practitioners due to its standardized approach, providing common terminology, formal planning process, and unified resource typing and documentation (Anderson, Compton, and Mason 2004). Nevertheless, concomitant concerns were also raised regarding its hierarchical and centralized authority, the difficulty of establishing accurate information and intelligence, and the lack of flexibility under rapidly changing environments during incidents (Buck, Trainor, and Aguirre 2006; Jensen and Thompson 2016; Tierney, Lindell, and Perry 2001; Waugh 2009).

With increased scholarly attention to *resilience*, a system's ability to absorb, mitigate, and recover from disturbances (Boin, Comfort, and Demchak 2010; Paton, Smith, and Violanti 2000); disaster management policies such as NIMS and ICS have been assessed for their efficacy in supporting adaptive performance of emergency response organizations. For instance, Bigley and Roberts (2001) argued that ICS, a primary component of NIMS, allows emergency managers and responders to be adaptive in terms of organizational structure and the transfer of authority and responsibilities. Further, Harrald (2006), through a comprehensive document review of the Hurricane Katrina response, claimed that both the principles of NIMS and other factors not covered by NIMS, such as improvisation, creativity, and adaptation, were necessary to successfully cope with challenging situations during disasters.

While general understanding of the role of incident management policies (e.g., ICS, NIMS) has deepened in the literature, the applicability of these frameworks to the healthcare sector has been limited due to distinct characteristics of hospital operations in the face of disasters (Boin and McConnell 2007; Bulson and Bulson 2018). Hospitals and healthcare systems that receive any type of US federal preparedness funding are required to operate in accordance with NIMS (FEMA 2006). In addition, as they receive injured or ill patients from public emergency services (e.g., search and rescue, emergency medical service), hospitals and their emergency departments (EDs) become an interface with public agencies governed by NIMS principles (Farmer and Carlton 2006). Despite the importance of regional hospitals as critical infrastructure for communities experiencing the hazards of a disaster, issues associated with the adoption of ICS in the healthcare domain need resolution. For example, researchers argue that ICS may not cover hospital-specific needs, such as mass casualty management, patient evacuation, and the mental health of hospital staff (Jenkins et al. 2009). Other areas for further consideration in hospital incident management policy include protecting critical care capabilities, maintaining surge capacity, planning staff assignments, and hospital-specific incident command system and training programs (Lynn et al. 2006; Meyer et al. 2018; Rodríguez and Aguirre 2006).

In order to better inform incident management policies that nurture resilient healthcare systems, it is crucial to understand the challenges and opportunities that exist with regard to resilient hospital incident management. However, such knowledge has been markedly limited to date. To address this gap, the present article aims to investigate resilient traits of a large regional hospital's recent response to a catastrophic disaster: Hurricane Harvey (2017). Our study employs two major safety perspectives: *Safety I* or analysis of what went wrong to identify challenges, and *Safety* II, the analysis of what went right, in order to document opportunities for safety improvement (Hollnagel 2014).

Background

Responses to large-scale wildfires that frequently occurred in California during the 1970s revealed many issues, such as differences in organizing mechanism, communication protocols, and multi-agency coordination (Dague and Hirami 2015). Addressing these recurring problems led to a cooperative program called Firefighting Resources of California organized for Potential Emergencies (FIRESCOPE). One outcome of this was ICS, which has been widely adopted in forest fire incidents since the early 1980s (Buck, Trainor, and Aguirre 2006).

As a standardized guideline for on-scene incident command for all types of incidents and hazards, ICS enables different response organizations to adopt a common organizational structure, coordinate between multiple jurisdictions and agencies, and follow organized processes for continuous incident action planning (Chang 2017; Son et al. 2018). Incident management organization is generally established in the incident command post (ICP) or emergency operations center (EOC). ICS consists of five major sections—command, operations, planning, logistics, and finance and administration—as shown in Figure 1. Incident commanders work with command staff and general staff of each section to plan and manage emergency situations, including, of course, major hurricanes.

Hurricane Harvey officially made landfall in Texas on August 25, 2017, striking Aransas County as a Category 4 hurricane and travelling inland in a northwest direction before winds halted and pushed the storm southeast toward the Gulf. Harvey was a particularly slow-moving storm and had backtracking path that kept City of Houston inundated with rain for far longer than normally anticipated. While stalled over the Texas coast, Harvey dropped record-setting rainwater of more than 60 inches and caused unforeseen flooding, resulting in nearly 800,000 evacuees (Texas Commission on Environmental Quality 2018). The estimated total cost incurred by Harvey was $125 billion USD, second only to Hurricane Katrina among costly natural disasters (National Hurricane Center 2018). To examine the characteristics of a resilient hospital in a real-world disaster, Hurricane Harvey was selected due to its recency and accessibility to the authors of the present study.

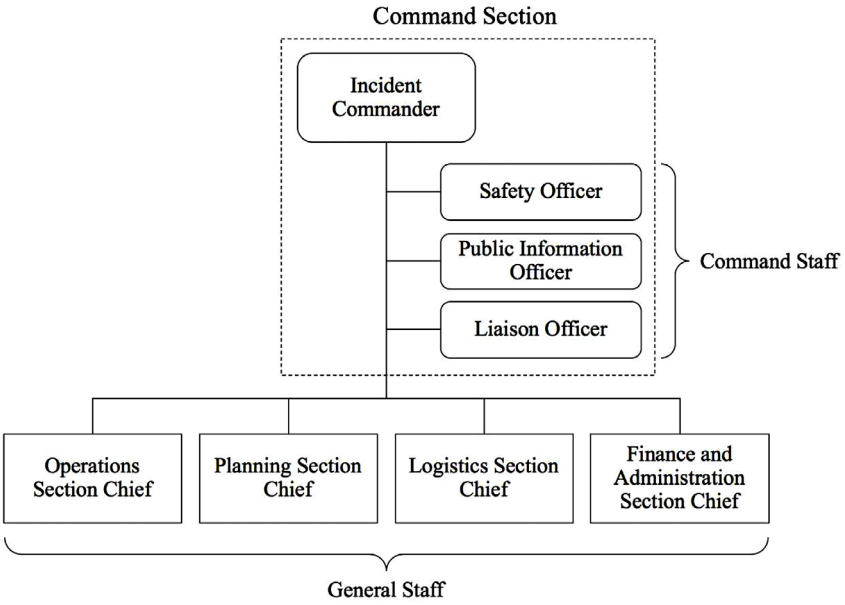

Figure 1. A generic structure of an incident management organization. Command staff members, such as safety officer, public information officer, and liaison officer, provide assistance to the incident commander when they work with representatives from other functional sections (e.g., section chief).

Given the current threat landscape, the importance of resilient hospital incident management is clear. As an emerging concept for increasingly complex social and technical systems, resilience has been defined, operationalized, and measured in various scientific disciplines (Hosseini, Barker, and Ramirez-Marquez 2016). From a disaster risk management perspective, resilience is generally defined as an ability of a social and physical system to prepare for, respond to, and recover from the effects of a disaster incident in a timely and efficient manner (Alexander 2013; United Nations International Strategy for Disaster Reduction 2009).

As an abstract construct, an examination of resilience or resilient performance of systems often requires two safety viewpoints. *Safety I*, a traditional and dominant view of safety, focuses on system failures and instances where things went wrong during an incident, and stresses corrective actions to fix such issues (Hollnagel 2014). The application of the *Safety I* approach to hospital disaster response has been effective in revealing problems experienced by hospitals, such as staff shortages, loss of utilities, insufficient supplies, and lack of regional communication (Downey, Andress, and Schultz 2013; Klein, Rosenthal, and Klausner 2005; Milsten 2000). Recently, the safety paradigm has shifted towards *Safety II* to highlight positive adaptations or workarounds in daily operations or instances where things go right, in addition to what goes wrong (Hollnagel 2014). *Safety II* treats human operator flexibility as an indispensable attribute of a resilient system

(Sujan, Huang, and Braithwaite 2017). While the *Safety I* framework is typically applied in the area of hospital disaster management, the *Safety II* approach is not often used. In order to best inform effective hospital disaster planning, both approaches should be employed in order to produce a more holistic and balanced investigation.

Method

To elicit both challenges and successes experienced by hospital incident management in Hurricane Harvey, semi-structured interviews were conducted with personnel who were involved in the incident command center of a large regional hospital located in southeastern Texas. The hospital safety office first identified a pool of potential participants who were involved in the hospital's incident response to Harvey. The potential participants were individually contacted by one of the authors via email to ask for their voluntary participation in a semi-structured interview focused on the hospital's response to the hurricane. Of the twenty potential participants initially contacted, eight responded and six agreed to participate in the study. After the first round of interviews, non-responsive candidates were contacted again; no additional participants were recruited. Participants had all received training in response management and their roles covered the entire command structure of the hospital—from the executives (e.g., vice presidents) who served as an incident commander to the staff responsible for operations, health and safety, and facilities management (Table 1). The research protocol of the current study was approved by the hospital's institutional review board (IRB No.: Pro00018680).

Table 1. A list of interviewees

Participant No.	Position	Experience	Certification
P01	VP, Quality and Safety	25 years	ICS-300†
P02	VP, Operations	2 years	ICS-300
P03	Operations Admin, Health Supervisor	6 years	ICS-300
P04	Operations Admin, Safety Officer	27 years	ICS-300
P05	Supervisor, Compliance and Environment, Health, and Safety	1 year	None
P06	Manager, Environment, Health, and Safety	11 years	ICS-300

† ICS-300, Intermediate ICS for Expanding Incidents, is an advanced emergency management training program required for an incident of a mid to high level of complexity (FEMA 2007).

Semi-structured interviews were conducted with the participants during the normal workday in the hospital in September 2018. One faculty member and one postdoctoral researcher at the hospital knowledgeable in the incident management domain and qualitative research methods served as the primary interviewers and were supported by one graduate student for note taking and audio-recording of interviews.

The interviewers used a set of questions focused on the major aspects of disaster resilience (i.e., functions to overcome challenges and achieve organizational goals) as a guide for the interview. Table 2 represents the interview themes and associated questions asked in the interviews. Where applicable, new questions were introduced based on emerging topics as the interview progressed.

Table 2. Questions used in semi-structured interviews

Aspect	Related questions
Personal and organizational context	• What was your role in response to Harvey? • Can you describe the structure and composition of the response organization you worked for?
Challenges and successes during the incident	• What were the major challenges of Harvey that you had not expected or experienced from previous incidents? • How did you overcome such challenges?
Goals of IMT s	• What were the major goals that you tried to achieve during Harvey and how did you accomplish those goals?
Functions of IMTs	• How did you make sense of evolving situations during Harvey? • What key decisions did you make to solve problems in Harvey and how? • Can you tell us about procedures, plans, or guidelines you used in response to Harvey? • How did you utilize resources to perform response actions?

The interviews took approximately forty minutes on average. After informed consent was obtained from participants, the interviewers first requested a brief overview of each respondent's professional career and specific roles that were assumed during Harvey. Interviewers then followed the semi-structured interview protocol. Not all questions were asked during all interviews. The audio-recordings of the interviews were transcribed by an external professional service.

To capture emerging topics regarding characteristics of resilient hospital incident management, a thematic analysis method was adopted (Braun and Clarke 2006). The codebook used was derived from a larger project studying the regional

response of government-led EOCs in the southeast Texas region during Harvey (Son et al. 2019). Since hospitals are a subset of regional emergency operations, the codebook used in the present study was streamlined based on its relevance to the hospital context. The transcripts were coded in an iterative manner by two study authors, who were also responsible for reducing the codebook. After individual coding was completed, the coders discussed disagreements and revisited the coding results to clarify discrepancies. A kappa statistic was calculated using MAXQDA 2018[1] to evaluate concurrence between the coders on individual transcripts. The kappa value between the two coders was 0.623, indicating a moderate to significant level of agreement in coding of the transcripts. Finally, the coding of the first author was used to report the results in this article.

Results

The analysis yielded two sets of findings regarding resilient hospital incident management during Harvey. The first set consists of demanding situations and major events that occurred and hospital goals under such conditions (Table 3). The second set of findings contains specific challenges (i.e., *Safety I*) and opportunities (i.e., *Safety II*) that existed in hospital incident management in relation to six aspects of disaster resilience (Table 4). In the interest of highlighting the context and consequences of incident command decisions during a major event, we selectively include some of the transcribed respondent comments.

Table 3. Situations faced and goals pursued by the hospital staff during Harvey

Noticeable events during Harvey	Goals of the hospital
• **Massive rainfall and flooding** • **Severely limited access to hospital** • **Shutdown of local clinics for a longer period** • **Patient surge (e.g., dialysis) in the ED** • **Loss of electric power in some areas** • **Contamination of sterile supplies and patient samples** • **Inundation of the basement**	• **Patient health and safety** • **Stabilization of hospital operations** • **Maintaining hospital structural integrity**

Difficulties Faced and Goals Pursued During Harvey

Harvey resulted in a massive rainfall and subsequent flooding in the affected areas. An unprecedented amount of rainfall and flooding created difficult situations both outside and inside the hospital. With respect to external factors, interviewees

1 MAXQDA Analysis Pro is software made in Berlin, Germany.

Table 4. Opportunities and challenges identified from the hospital response to Harvey

Aspect	Opportunities/Strengths	Challenges
Organizational structure and functions and individual roles	• Established multiple incident command centers for respective accountability. • Functional flexibility of turning into outpatient-centered operations. • A smooth role transition from normal duties to incident.	• Excess endeavors to coordinate multiple incident command centers. • Concentration of resources on specific areas of care (e.g., dialysis).
Communication and situational awareness	• Availability of various formal and informal communication channels. • Regular conference calls and briefings as a vehicle to transfer knowledge across shifts.	• Need for hospital-wide notification system. • Lack of direct communication between medical facilities. • Incompatibility between different hospital information management systems.
Operating plans and protocols	• Skipped administrative operating procedures for urgent work requests. • Accepted food donation from private and non-government organizations. • Maintained critical patient reporting protocol.	• Difficulty of following formal planning process (e.g., NIMS). • Overly specific requirements for reimbursement from federal funding.
Human and physical resources (staff, space, and supplies)	• Sufficient staffing capacity. • Flexible utilization of spatial resources for patient care and staff welfare. • Mobilizing back-up supplies and equipment to sustain hospital operations.	• Increased fatigue and anxiety of hospital staff. • Issues with ad hoc use of spatial resources (e.g. helipad, sleeping space). • Hazards from back-up equipment (e.g., emergency generator) and limitations in supply stock (e.g., fuel).
Lessons learned from previous incidents	• Reflecting lessons into current preventive and protective measures. • Regular inspections and drills for disaster preparedness.	• Lack of community-wide effort to incorporate lessons into community infrastructure.
Leadership and high-level decision-making	• Walk-arounds and hands-on interaction with frontline staff to get more accurate operational needs and to make relevant decisions.	• Delayed declaration of emergency within hospital. • Lack of incident command leadership among neighboring hospitals.

stated that the general public's access to medical facilities (e.g., local and regional healthcare providers) was severely limited due to road closure, and that most local clinics (e.g., dialysis providers) were closed for an extended period of time even after Harvey dissipated. As a result, the study hospital experienced a patient surge, including those who had to receive dialysis, especially in the ED. Inside the hospital, some areas lost electric power and the sterile supplies department was contaminated due to ruptured pipes. In addition, the hospital's basement was inundated with rainwater.

Under these adverse situations, the hospital incident command staff pursued common goals. These included ensuring the health and safety of patients, stabilizing hospital operations, and maintaining the hospital's structural integrity. In particular, the interviewees were highly attuned to the possibility of water seepage as it might cause critical problems in the hospital's internal infrastructure (e.g., sanitation and power supply systems).

Opportunities for and Challenges to a Resilient Hospital Response to Harvey

Six aspects of resilient response to a large-scale disaster emerged: i) organizational structure and functions and individual roles, ii) communication and situational awareness, iii) operating plans and protocols, iv) human and physical resources, v) lessons learned from incidents, and vi) leadership and high-level decision-making.

Organizational Structure and Functions and Individual Roles

The hospital adapted its organizational structure and functions and staff roles, which contributed to its resilience. First, while public agencies and jurisdictions manage their response generally at one central EOC, the study hospital established two incident command centers during Harvey for the first time: one for overall operations and the other for facility management. Across participants, there was ambivalence regarding the benefits and disadvantages of this approach. According to the respondents, this distributed model resulted in a more efficient response, but some participants cited problems with communication and coordination.

The respondents indicated that the hospital was flexible in turning its operational focus from inpatient care to outpatient service to accommodate the increased ambulatory patient flow. The ED initially provided continuous dialysis service, but as the hurricane progressed, the dialysis patients had to be referred to other facilities in order to maintain the hospital's patient care resource balance.

Another resilience trait was hospital staff's perception that their role did not change during the disaster. However, the interviewees offered some examples of role adjustment, such as on-call executive personnel assuming the incident commander role and a public relations staff who served as a public information officer.

> [The incident commander] was able to have the people do the things that they normally do. We didn't have to take a job that we were not comfortable with.
>
> I didn't feel any difference from other normal days, truthfully.

Communication and Situational Awareness

Study respondents emphasized the importance of timely and accurate communication and situational awareness within the hospital and between healthcare organizations and government agencies. Factors that contributed to effective and efficient information management included the availability of various means of communication and regular conference calls and briefings for knowledge transfer within the hospital.

Varied communication channels (e.g., direct phone call, in-person conversation, text messages, email) were used to understand what was occurring within the facility and issues needing resolution. However, a respondent pointed to a major need for a mass notification system capable of communicating incident information and alerts through multiple channels for timely, unified situational awareness.

Additionally, there were multiple shifts involving various disciplines in the hospital's main incident command center. Interviewees viewed regular conference calls and briefings as a primary vehicle to transfer situational knowledge throughout the event. In order to accommodate this, the hospital incident command center held campus-wide conference calls to integrate and disseminate updated information regarding response needs and operating status.

> I think the common operating picture was pretty well formed because we had multiple opportunities. For instance, [our hospital] had every day at 11:10 a.m. a daily briefing with all the leads around the hospital, both our patient care leads and our ancillary leads, and we talked about all the needs in the house.

While communication inside the hospital was active during the disaster, there were insufficient interactions between the hospital incident command center and the jurisdictional (e.g., municipal) EOC. In particular, when the hospital needed to understand the operational status and capacity (e.g., bed availability) of other hospitals, such communication was mediated by the jurisdictional EOC, which hindered hospital-to-hospital interaction.

> If our incident commander or one of us had an issue, we would have called it into the central EOC. If a patient was going to be needed to be transferred, transfers were handled through [the jurisdiction's] central command.

As part of jurisdictional emergency operations in a large-scale event, hospitals are required to use a government-based platform (e.g., *WebEOC*[2]). Notwithstanding its intent to centralize incident information, the government-centered program was not compatible with hospital-based information systems. For instance, the hospital was using hospital-based emergency information systems, such as *EMResource*[3] and *EMTrack*,[4] to monitor hospital status and track patients across medical facilities. An interviewee, however, indicated that these systems were not compatible or harmonized with the government-adopted system. In addition to the government-hospital information system interface problem, there is a similar incompatibility issue regarding the interface between the hospital emergency information systems and an electronic medical record (EMR)/electronic health record (EHR) system commonly used for everyday clinical operations.

> If I'm in WebEOC, I literally have to leave WebEOC go to EMResource to see what the status is. There is no page on WebEOC where I can look and say what is the status. [...] The interface between those two databases, in my humble opinion, is not as robust as it could be in this type of event.

> There is no easy interface between Epic (an EHR application) and EMTrack, or whatever patient tracking. So what that leads to is either redundancy or delay.

Operating Plans and Protocols

Although the hospital adopted formal incident management guidelines, such as NIMS, some interviewees claimed that they did not follow the planning process and forms specified in NIMS. Rather, their responses to emerging needs were carried out pragmatically and in an informal and opportunistic manner to find and fix emerging problems. Importantly, one respondent stated that documentation requirements for federal fund reimbursement were too difficult to adapt.

> There was an informal type of a planning session. They did not follow the formal process. They were supposed to have the [designated form] as far as planning for the next operational cycle but we did not use that form down here.

> I don't think there was an exact, specific book that was being followed 100 percent, to be honest. We were just making a general as-

2 Web-based software used to support the information and resource management among multiple response organizations.

3 A commercial software program that helps manage resource availability and operations status of medical facilities.

4 A commercial software program that aids in tracking patients and evacuees during a crisis.

> sessment and really figuring out what we're able to do and where we might have deficits in supplies, food, and all those things.
>
> I was very shocked to see the specific need for FEMA funding for damage. We found out that it was kind of a headache post-recovery. There was a lot of very specific documentation or specific things within the documentation that the federal government wanted that we couldn't necessarily provide.

Several instances were mentioned where hospital staff found that departure from required operating procedures were advantageous. In dealing with work requests, for example, interviewees said they often skipped the *Problem-Cause-Resolution (P-C-R)* procedure, a formal trouble-shooting system for hospital day-to-day operations. Similarly, the hospital accepted food donations from external private and non-governmental organizations, which they were not normally allowed to do.

> There was a P-C-R procedure of the work ticket. [...] And staff should be filling that out as part of the work order ticket closure process. We didn't do any of that. We didn't have the staff to sit down and type this stuff out.
>
> There were a lot of restaurants that started donating to us, and then we gave away free. [A fast food franchise] came over and gave us 2,000 sandwiches one day, and we went and handed those out, but we don't normally do that.

In contrast to deviating from operating procedures, continued compliance was sustained with mandatory protocols despite a deferral declaration. For example, the Centers for Medicare and Medicaid Services (CMS) granted the impacted region a moratorium on the federally mandated reporting of infections and other adverse events. Nonetheless, the hospital elected to report all events to the CMS, demonstrating an ability to maintain normal operations and compliance under pressure.

Human and Physical Resources

The interviews captured adaptive use of hospital resources: *staff*, *space*, and *supplies* (the three S's). First, the hospital maintained a sufficient staff pool before and during Harvey. To do so, the hospital called in staff, who were originally responsible for post-incident recovery efforts, to assist in immediate response activities. In addition, staff worked a double shift for high-demand areas, such as dialysis care. Also, there was additional support from non-clinical personnel and staff who worked beyond their job specifications.

> We had a stable labor pool. In fact, the labor pool was so packed at one point

that they were about to send people away, but then we said, 'No, no' because the need is going to happen later.

> There was a very generous staffing pool of people that were not in clinical side that I think helped relieve some of the stress. And there were some of the other duties that were utilized from other areas.

> We were always thinking about next 24 to 48 hours. Where are we going to get staff? How are you going to give some people some rest? In cases where we had some departments that were really critically short or in critical mood issues, where could we get them some relief?

Second, the hospital was flexible in utilizing physical space. A temporary clinic was organized to deal with excess influx of patients. A sterile supplies room was created ad hoc, since the original location was contaminated by ruptured pipes. For sleeping arrangements, hospital staff used waiting areas and unlocked offices to accommodate the increased staff volume. Commenting on sleeping arrangements for future disaster responses, an interviewee highlighted a need to pre-designate locations for rest and sleep. In addition, interviewees noted that some helicopter pilots were using a decommissioned helicopter pad instead of a newly built, but remote, landing space for faster patient transport in spite of associated risks.

A third type of resource adaptation concerned the use of supplies and equipment. For instance, the hospital experienced a loss of power in one of its buildings housing patient sampling laboratories. To sustain the laboratories and thus preserve the patient samples, the hospital mobilized emergency diesel generators. However, issues arose, such as generator exhaust emissions and an insufficient supply of diesel fuel. With the exception of power loss in some areas, one respondent stressed the strength of the hospital's cross-connected utility infrastructure (e.g., water, electricity), which prepared the system for major disruptions.

> We had generators stand by and fuel for 96 hours. But with the city being the mess, we would have lost power if there has been a delay before we got fuel.

> We're set up to adapt. Every building has the ability to power another building and to send water to another building. And it's a matter of just going out there and hooking it up. I don't think we ever had to rig anything.

Lessons Learned from Previous Incidents

The interviewees highlighted the benefit of applying experience gained from previous incidents regarding preventive and protective measures for hospital inci-

dent management systems. One successful adaptation was the prior installation of floodgates. Based on lessons learned from Tropical Storm Allison in 2001 (which inundated multiple large medical centers in the impacted region), the hospital had installed floodgates that sealed off entryways from floodwater. Critical emergency equipment (e.g., generators) was also moved from the basement. Furthermore, interviewees emphasized regular inspections and drills aimed at verifying readiness (e.g., fuel stock, floodgates) for potential flood risks.

> I was very happy to see the flood gates basically pay for themselves after they were installed after Tropical Storm Allison. Getting the flood doors closed and maintaining them went really smoothly. [...] We train on doors at [the hospital] at least every year. We make sure that the equipment is up and running.

While the hospital benefitted from past disaster experience, the respondents raised the need for a broader community-wide effort to apply lessons learned about community infrastructure beyond individual hospitals. They were especially concerned about managing elevated demands for patient care during a large-scale incident.

Leadership and High-Level Decision-Making

While participants acknowledged that the response and recovery were a collective task, hospital leadership was seen as having played a paramount role in coping with difficulties. It is noteworthy that hospital incident command center leaders were focused on staying in close interaction with public emergency responders. Such actions were helpful in assessing current needs, allocating resources in a pragmatic fashion, and facilitating situational awareness.

Nevertheless, our study also identified decision-making challenges for hospital leadership during Harvey. First, the incident commanders' delayed activation of the hospital's emergency operations plan prevented a portion of "ride-out staff," who were responsible for an immediate response, from returning to the hospital as hurricane conditions intensified. Second, interviewees opined that collaborative incident leadership among neighboring hospitals was lacking, which might be necessary for sharing required resources and maintaining close communication among them.

> A window was extremely small for people to do that (activate the emergency plan) and I think it caught people off guard. The only major vulnerability I could see from [the hospital] was that we didn't have a clear process for the release of staff before landfall.

> [An adjacent medical center] was calling a whole lot because they were trying to get some supplies or some activities in but it wasn't successful. [...] We went through a number of meetings during

> and after actions to talk about some of the challenges. [...] But formal processes for communication can be a challenge.

Discussion

Safety I and Safety II Evaluation of Hospital Incident Management

The findings of the current study highlight the importance of using both safety viewpoints (*Safety I* and *II*) in evaluating hospital operations during a large-scale incident. From a *Safety I* perspective, our study identified some recurrent issues experienced by hospitals during disasters. For example, an excess volume of dialysis patients, a loss of electric power, and staff shortages have been repeatedly cited (Downey, Andress, and Schultz 2013; Klein, Rosenthal, and Klausner 2005; Kopp et al. 2007; Murakami et al. 2015). The response to such challenges, however, appeared to be unduly reactive. The subject hospital and its local counterparts appeared to lack a sufficiently proactive and coordinative posture, as argued in the literature (Farmer and Carlton 2006; Timmins, Bone, and Hiller 2014).

Our findings also suggest a need to address interoperability between advanced emergency and healthcare information technologies. In particular, incompatibility between multiple emergency information systems (e.g., *WebEOC*, *EMTrack*) deserves further investigation due to its importance in cross-sectional communication and collaboration during disasters. Additional attention is also warranted to address the interface between the EHR applications and the emergency information systems given increased EHR adoption and its recognized advantages (Abir et al. 2012).

This study also showed that the *Safety II* approach could shed light on the resilience of hospital incident management teams. In terms of organizational structure, the study hospital created two incident command centers to handle matters specific to facilities, a critical component of the hospital operations. Although the decentralized decision-making process enabled the facility's command center to quickly address rising needs, the discontinuity in incident command created an additional communications hurdle. This is consistent with research findings that adaptations of a normal practice entail a trade-off between multiple goals across different levels of an organization (Hollnagel 2009; Woods and Branlat 2011) and with findings regarding resilience in the use of operating procedures (Furniss et al. 2011; Wachs and Saurin 2018). The hospital exhibited adaptive behavior by deviating from a formal work order procedure to quickly address urgent issues. However, the hospital continued to abide by its CMS reporting policy even though it was exempted, showing robustness in implementing the required protocols.

Consistent with previous studies (Autrey and Moss 2006; Son et al. 2020; Wolbers and Boersma 2013), our research found that maintaining collective situational awareness was an essential element of a resilient system that understands and

rapidly responds to changing needs during disturbances. In particular, frequent rounding of the facilities incident commanders to increase situational awareness and to boost staff morale is recommended as a practice for hospital leadership. The study also confirmed a need for a hospital-wide notification system operating in real time to create unified internal awareness of conditions in addition to external situation awareness.

The adaptive use of hospital resources in terms of the three S's (i.e., staff, space, and supplies) observed in our study is consistent with the characteristics of a resilient healthcare organization documented in the literature (Hick, Hanfling, and Cantrill 2012; Son et al. 2019). Since adaptive or improvisational behaviors (e.g., staff sleeping in unlocked offices) during an adverse event may reoccur, leading to undesirable outcomes (Hollnagel 2008), best practices need to be institutionalized into formal operating procedures to increase benefits and reduce associated risks.

Finally, it is important to note that, by and large, lessons from previous flooding events were helpful in improving the level of disaster preparedness in the study hospital. However, our research provides presumptive evidence for the need to increase community-wide disaster planning efforts (see also Burkle et al. 2007). It is particularly important that professionals across healthcare systems and jurisdictional emergency services work in tandem to effectively deal with chronically vulnerable populations (e.g., dialysis patients) and emerging public health threats (e.g., pandemic disease) from disasters.

Implications for Disaster Management Policies

Integrating findings from the two safety perspectives, we propose two areas of incident management policy warranting attention. First, we found that the ICS incident action planning process was not adequately implemented by hospital incident operations. Reasons for this may include the hospital's internal planning and communication processes (e.g., reliance on a pre-scheduled morning conference call) that serve the purpose of understanding ongoing situations and deciding what actions to take. Hospitals should consider how ICS can be incorporated into their existing planning policies and practices under disaster conditions.

Second, individual communities should assess the utilization of government incident management organizations for inter-hospital communication. In the present case, communication among multiple hospital incident command centers was mediated by the jurisdiction's EOC, hindering direct coordination and collaboration between hospitals. Given the relatively hierarchical and vertical nature of NIMS (Jensen and Thompson 2016), and the relatively more collaborative hospital environment (Christian, Kollek, and Schwartz 2005), ways to promote horizontal communication among healthcare organizations during a disaster should be developed.

Limitations of the Current Study

Our study examined the response to Harvey almost a year after the hurricane struck, which may have contributed to recall bias. In addition, the responses were self-reported narratives of staff members who worked in a single hospital throughout the event. Future research should compare resilient responses among multiple hospitals and healthcare systems to understand patterns, variabilities, and context-specific strategies. Another study limitation was the small number of respondents (n=6). However, it should be noted that most common government and healthcare EOCs are small (fewer than 10 people). We included in the sample personnel from almost every level of the study hospital's incident command. To address these limitations, future research might employ complementary methods, such as direct observation or video-recording response management processes following a major disaster.

Conclusion

This article incorporates two resilience viewpoints (i.e., *Safety I* and *Safety II*) in assessing hospital incident management during a large-scale disaster. Based on healthcare emergency professionals' experience during Hurricane Harvey, the case study attempted to identify what "went right" and what "went wrong" in hospital incident management from six perspectives: organizational structure and individual roles; communication and situational awareness; operating plans and protocols; hospital resources; lessons learned; and leadership and high-level decision making. The study confirmed that chronic challenges to hospital disaster planning and management should be addressed using both hospital and incident management policy perspectives. The opportunities and practice improvements identified in our case study require further exploration for their incorporation into hospital disaster preparedness programs in order to make hospitals and healthcare systems more resilient in large-scale disaster events.

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References

Abir, Mahshid, Farzad Mostashari, Parmeeth Atwal, and Nicole Lurie. 2012. "Electronic Health Records Critical in the Aftermath of Disasters." *Prehospital and Disaster Medicine* 27 (6): 620-22. doi:10.1017/S1049023X12001409.

Alexander, David E. 2013. "Resilience and Disaster Risk Reduction: An Etymological Journey." *Natural Hazards and Earth System Sciences* 13 (11): 2707–16. doi:10.5194/nhess-13-2707-2013.

Anderson, Anice I., Dennis Compton, and Tom Mason. 2004. "Managing in a Dangerous World—the National Incident Management System." *Engineering Management Journal* 16 (4): 3–9. doi:10.1080/10429247.2004.11415260.

Autrey, Pamela and Jacqueline Moss. 2006. "High-Reliability Teams and Situation Awareness: Implementing a Hospital Emergency Incident Command System." *The Journal of Nursing Administration* 36 (2): 67–72.

Bigley, Gregory A. and Karlene H Roberts. 2001. "The Incident Command System: High-Reliability Organizing for Complex and Volatile Task Environments." *Academy of Management Journal* 44 (6): 1281–99. doi:10.5465/3069401.

Boin, Arjen, Louise K Comfort, and Chris C Demchak. 2010. "The Rise of Resilience." In *Designing Resilience: Preparing for Extreme Events*. Edited by Louise K. Comfort, Arjen Boin and Chris C. Demchak, 1–12. Pittsburgh, PA: University of Pittsburgh Press.

Boin, Arjen and Allan McConnell. 2007. "Preparing for Critical Infrastructure Breakdowns: The Limits of Crisis Management and the Need for Resilience." *Journal of Contingencies and Crisis Management* 15 (1): 50–59. doi:10.1111/j.1468-5973.2007.00504.x.

Braun, Virginia and Victoria Clarke. 2006. "Using Thematic Analysis in Psychology." *Qualitative Research in Psychology* 3 (2): 77–101. doi:10.1191/1478088706qp063oa.

Buck, Dick A., Joseph E. Trainor, and Benigno E. Aguirre. 2006. "A Critical Evaluation of the Incident Command System and NIMS." *Journal of Homeland Security and Emergency Management* 3 (3): 1–27. doi:10.2202/1547-7355.1252.

Bulson, Julie and Tim Bulson. 2018. "An Independent Review of Several Successful Hospital Incident Command System (HICS) Implementations and Lessons Learned." *COJ Nurse Healthcare*. doi:10.31031/COJNH.2018.03.000553.

Burkle, Frederick M., Edbert B. Hsu, Michael Loehr, Michael D. Christian, David Markenson, Lewis Rubinson, and Frank L. Archer. 2007. "Definition and Functions of Health Unified Command and Emergency Operations Centers for Large-Scale Bioevent Disasters within the Existing ICS." *Disaster Medicine and Public Health Preparedness* 1 (2): 135–41. doi:10.1097/DMP.0b013e3181583d66.

Chang, Hsien-Ho. 2017. "A Literature Review and Analysis of the Incident Command System." *International Journal of Emergency Management* 13 (1): 50–67.

Christian, Michael D., Daniel Kollek, and Brian Schwartz. 2005. "Emergency Preparedness: What Every Health Care Worker Needs to Know." *Canadian Journal of Emergency Medicine* 7 (5): 330–37. doi:10.1017/S1481803500014548.

Comfort, Louise K. and Naim Kapucu. 2006. "Inter-Organizational Coordination in Extreme Events: The World Trade Center Attacks, September 11, 2001." *Natural Hazards* 39 (2): 309–27. doi:10.1007/s11069-006-0030-x.

Coronese, Matteo, Francesco Lamperti, Klaus Keller, Francesca Chiaromonte, and Andrea Roventini. 2019. "Evidence for Sharp Increase in the Economic Damages of Extreme Natural Disasters." *Proceedings of the National Academy of Sciences* 116 (43): 21450–55. doi:10.1073/pnas.1907826116.

Cruz, Miguel A., Ronald Burger, and Mark Keim. 2007. "The First 24 Hours of the World Trade Center Attacks of 2001—the Centers for Disease Control and Prevention Emergency Phase Response." *Prehospital and Disaster Medicine* 22 (6): 473–77. doi:10.1017/S1049023X00005288.

Dague, Dale and Patricia Hirami. 2015. "The United States Forest Service's Incident Command System 40 Years On: From Domestic Wildfires to International Disaster Response." *Unasylva* 66 (243/244): 79.

Downey, Erin L., Knox Andress, and Carl H. Schultz. 2013. "Initial Management of Hospital Evacuations Caused by Hurricane Rita: A Systematic Investigation." *Prehospital and Disaster Medicine* 28 (3): 257–63. doi:10.1017/S1049023X13000150.

Farmer, J. Christopher and Paul K. Carlton. 2006. "Providing Critical Care During a Disaster: The Interface between Disaster Response Agencies and Hospitals." *Critical Care Medicine* 34 (3): S56–S59. doi:10.1097/01.CCM.0000199989.44467.2E.

Federal Emergency Management Agency. 2004. *The National Incident Management System.* 1st ed. US Department of Homeland Security.

———. 2006. *Fact Sheet-NIMS Implementation Activities for Hospitals and Healthcare Systems.* US Department of Homeland Security. https://www.fema.gov/pdf/emergency/nims/imp_hos_fs.pdf.

———. 2007. *Fact Sheet: NIMS ICS-300 Training: Who Must Take It, What It Covers.* US Department of Homeland Security. https://www.fema.gov/pdf/emergency/nims/ics_300_fs.pdf.