IMPROVING HOSPITAL SURVIVABILITY:

TOOLS TO INFORM HOSPITAL PLANNING AND DESIGN

by

James B. Goetschius

A dissertation submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Disaster Science and Management

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ABSTRACT

The scale and impact of recent natural disasters and the threat of climate change has increased awareness of the vulnerability of our built environment to disruptions. Major storms, such as Hurricanes Katrina and Sandy, have shown how these and other disaster events can negatively affect our health care infrastructure. Such disruptions are not new and are likely to continue in the future. National efforts, like the National Infrastructure Protection Plan and the National Health Security Strategy, recognize medical treatment facilities as key components of community emergency response for the preservation of the health, safety, and welfare of the nation's citizens. To be effective, hospitals must be prepared to remain operational during and after a disaster.

We need a more comprehensive understanding of hospital functionality and the risks they face in order to devise more effective ways of ensuring the continuity of health care operations. This project sought to develop and apply lessons from disaster science and hospital emergency management to medical facility planning and design for the purpose of improving the survivability of nonstructural systems to increase the likelihood that medical treatment facilities will remain operational following disasters. Three tools were developed to improve the manner in which planners, designers, health care professionals, and emergency managers consider hospitals and their survivability during and after disaster events. The project’s objective is to develop a policy recommendation to the U.S. Army that will improve the manner in which the Service approaches the planning and design of military medical facilities. The tools

are an influence diagram, hazard vulnerability mitigation framework (HVMF), and illustrative optimization model.

The influence diagram improves our understanding of the elements and influences that bear on hospital functionality. It provides a comprehensive view of the internal and external systems necessary to maintain the continuity of health care operations. The HVMF establishes a systematic approach to understanding hazards, their characteristics, exposure, vulnerability, and consequences as a basis for identifying protective actions to increase hospital survivability. The optimization model is a scenario-based decision support tool that illustrates the importance of planning and modeling in understanding complex problems. It demonstrates the quantification of a loss of service and its impact on the delivery of health care.

The findings rely primarily on the qualitative analysis of expert panels consisting of health care professionals whose comments and recommendations led to the improvement and refinement of the influence diagram and HVMF. Additionally, secondary analysis of qualitative and quantitative data gathered from focus groups of medical treatment facility staff members experienced in hospital emergency management provided insights into hospital functionality, hospital support to communities, and the priority of services and support systems during disasters.

The research led to several observations. First, hospitals are strategic assets for the communities in which they operate. They have capabilities that are either unique or available within a limited number of organizations in a particular jurisdiction. Hospitals also serve non-traditional roles during disasters such as providers of shelter, food, water, information, pharmaceuticals, and supplies. Second, hospital functionality during disruptions is not simply about resources but also the flexible arrangement of those resources and organizational adaptability to meet changing health care demands. Third, the functional relationships among the diverse hospital systems can be captured in an influence diagram providing a graphical representation of the possible vulnerable elements and implications of failure. Fourth, the HVMF provides context for hazards, vulnerabilities, and possible protective actions to increase the survivability of hospital systems. Fifth, optimization models, with the limitations of their completeness, assumptions, data quality, and accuracy, provide insights into the process and complexities of problem solving. Sixth, having a comprehensive understanding of risks and identifying protective actions is different from prioritizing those actions and making capital investment decisions. The tools and findings from this research support informed decisions, but they do not recommend courses of action or solutions.

The project led to the identification of three key recommendations to improve the manner in which the U.S. Army approaches health care facility planning and design. First, stakeholders should determine what role the hospital will have in community disaster response and incorporate that during planning and design. Second, the design team should maximize support of operational flexibility in facility planning and design. Third, we should apply a holistic approach to understanding risk that entails a comprehensive analysis of threats, exposure, vulnerabilities, and consequences so that mitigation and preparedness actions are grounded in the specific circumstances of a facility or organization. Code compliance is the baseline, not the end state. Combined, these recommendations tie planning and design decisions to stakeholder expectations for the continuity of hospital operations. They acknowledge the importance of internal and external systems for flexible health care delivery to meet changing patient demands. Finally, they recognize the need to base protective actions in a comprehensive analysis of threats, vulnerabilities, and consequences.

Chapter 1

INTRODUCTION

Large scale disasters negatively affect the infrastructure of whole communities. Power is lost, transportation networks are damaged, and large numbers of buildings are destroyed or severely damaged. The devastation can also affect health care infrastructure, including hospitals, clinics, doctor's offices, and pharmacies. For people with chronic conditions or in need of medical care, the loss of these services can extend the period of disruption well beyond the occurrence of the precipitating event.

The primary purpose of this research effort is to advance health facility planners' understanding of hospital functionality and the systems necessary to maintain operations. Hospitals are subject to disruptions, but their important role in community emergency response means they must remain open and functional during disasters, which makes their survivability critical. Toward that end, we need to improve our understanding of how to apply mitigation and preparedness activities to increase the likelihood our medical treatment facilities will be available when we need them.

1.1 Problem statement

The problem motivating this research is how planning and design decisions affect the survivability of nonstructural systems in medical treatment facilities. Hospitals are systems of systems. Some systems and components are more important than others for overall hospital resilience. A particular component may be a single point of failure for the entire system, which can affect other systems that are either dependent or interdependent on the failing system. These relationships extend to external critical infrastructure and logistics functions. Disruptions to external resources can negatively affect a hospital's operations, also. To understand the possible sources of failure and how failures may cascade, decision makers need to understand the systems, their exposure to hazards, their vulnerabilities, their capabilities, options for reducing risk, and options for adapting to disruptions.

1.2 Motivation

The last three decades have seen an increased number of natural disasters around the world with greater numbers of people affected and rising costs associated with resulting damages (EM-DAT, 2012). These events, plus the threats posed by technological and human-induced hazards, regularly disrupt lives and livelihoods. Emergency management practices are designed to reduce or eliminate the effects of these hazards, protect lives and property, and return communities to a state of normalcy as quickly as possible. However, inherent in an event characterized as a disaster is the fact that available resources will be overwhelmed and communities will need to pull together, along with outside assistance, to provide an adequate response.

Among those community resources that are essential for a disaster response are health care organizations. All disasters are public health emergencies. Individuals who are affected by a disaster have increased risks to their health through exposure to disease, chemicals, inadequate sanitation, contaminated food, or the natural elements. In addition, many people receive injuries during disasters that require medical interventions. Hospitals, in particular, play a critical role in providing health care to the seriously ill during disasters.

Because of their importance as a community resource, health care facilities are widely recognized as critical infrastructure and emergency response assets. Their importance is noted by their inclusion in the U.S. National Infrastructure Protection Plan (U.S. Department of Homeland Security, 2009). This characterization as critical infrastructure accepts that in addition to being necessary for an adequate response, medical treatment facilities can also be victims of a disaster. The infrastructure protection plan puts emphasis on establishing programs and practices for strengthening primary and support facilities to ensure they will continue to function during and after a major event.

1.3 Objectives

The objective of this research is to develop and apply lessons from disaster science and hospital emergency management to medical facility planning and design for the purpose of improving the survivability of nonstructural systems to increase the likelihood that medical treatment facilities remain operational following disasters. The research seeks to develop a set of tools intended to inform a policy recommendation to the U.S. Army that may influence the manner in which the Service approaches the planning of military medical facilities.

1.4 Scope and Context

The research develops tools and findings grounded in science that will serve as the basis for recommendations to improve the manner in which the planning and design of hospitals is conducted. They are intended to be illustrative of the insights that can be gained from analysis. The tools are an influence diagram, a hazard vulnerability mitigation framework (HVMF), and an optimization model. Findings addressing community support and hospital functionality are derived from the analysis of expert panels of health care professionals and focus groups from the 2000-2001 Hospital Rehabilitation, Impediments, and Incentives study (Connell, 2003; Aguirre, Dynes, Kendra & Connell, 2005). The influence diagram and HVMF have direct applicability to the planning and design processes. The optimization model has application as a decision support tool, but its inclusion in this study is primarily to illustrate the role nonstructural systems play in hospital functionality and post-disruption decision making. The qualitative analysis of expert opinion and practitioner experience regarding disaster operations and emergency planning in hospitals deepens our understanding of the hospital functionality and community support during disasters. The tools and findings are described in Chapter 4.

The research draws on expert knowledge from both the military and civilian medical communities. The application of the tools focuses on military hospitals of all sizes in an all-hazards context, but the methods and results are applicable to civilian facilities, as well. Similarly, there are useful lessons for other non-hospital health care facilities.

1.5 Overview of the Research Approach

The approach to this research takes disparate pieces of information and frames of understanding to improve the planning and design of hospitals to make mitigation, preparedness, response, and recovery better. This approach is not typical and provides a unique view of nonstructural systems and their role in hospital operations.

The tools developed through this research broaden stakeholder understanding of the elements necessary to maintain a functioning hospital during a disaster and their relationships to one another. They provide the medical community with a systematic method of evaluating hazards and vulnerabilities in the context of continuous medical care. They offer a method of considering mitigation and preparedness options relying on scenario based optimization. They provide insights from the qualitative analysis of focus group interviews into the way hospitals meet changing health care demands and support their communities. The tools and findings support the development of a policy recommendation intended to improve the U.S. Army's approach to increasing the survivability of hospital operations during disasters through adjustments to the facility planning process that would be preserved through design and construction to facility handover. Maintaining the disaster related planning assumptions and guidance throughout the project to health care operations supports the delivery of health care and the continuity of hospital operations during disruptive events.

1.6 Organization of the Dissertation

To make navigating the dissertation easier, it is divided it into four primary chapters:

- Chapter 2: Context
- Chapter 3: Methodology: Data Collection and Analysis
- Chapter 4: Findings and Tools
- Chapter 5: Conclusions, Future Research, and Contributions

Chapter 2 provides a broad overview of the aspects of hospital preparedness associated with functionality and capacity with an emphasis on nonstructural systems.

This is accomplished by describing the national context in which hospital emergency management is performed followed by a discussion of threats and the manner in which hospital capacity and functionality are characterized. Next, a short history of hospital evacuations in the U.S. and the evacuation decision process are given along with a section detailing the influence nonstructural systems have on hospital operations. Finally, a summary of key regulatory requirements related to military medical facilities and nonstructural systems is provided.

Chapter 3 describes the research methods that were applied to the development and refinement of the tools that inform the creation of the policy recommendation to improve the U.S. Army's approach to the planning and design of health care facilities. It also describes the analysis from which the findings were derived.

Chapter 4 describes the tools and findings from the research. It explains the development and refinement of the influence diagram and the HVMF. It also describes the findings from the expert panels and Hospital Rehabilitation, Impediments, and Incentives project focus groups. The chapter concludes with an examination of an optimization model that illustrates the challenges associated with quantifying the risk and impacts of a service disruption to hospital operations.

Chapter 5 addresses the conclusions, future research, and contributions of the project. It identifies the observations and recommendations drawn from the research findings that inform policy changes intended to improve hospital planning and design, describes next steps in operationalizing the tools developed through this research, and explains how the research advances our knowledge of hospital systems and risk.

The dissertation culminates with the appendices. They are provided to support the main text and give the reader additional information about the subject matter.

Among the appendices are a list of acronyms (Appendix A); glossary; capabilities associated with the National Health Security Strategy, National Standards for State and Local Planning, and National Guidance for Healthcare Systems Preparedness; interview guides, handouts, and surveys used for the expert panels and focus groups; results of the quantitative analysis, and preliminary steps in putting the HVMF into practice.

Chapter 2

CONTEXT

The scale and impact of recent natural disasters and the threat of climate change has increased awareness of the vulnerability of our built environment to disruptions (National Climate Assessment and Development Advisory Committee, 2013). Major storms, such as Hurricanes Katrina and Sandy, have shown how these events can negatively affect our health care infrastructure (Aguirre et al., 2005; Rodriguez & Aguirre, 2006; Gray & Hebert, 2007; Pickett, 2009; Fink, 2012). These disruptions are not new (Auf der Heide, 1996; Milsten, 2000; Sternberg, Lee & Huard, 2004) and are likely to continue.

Hospitals must be prepared to remain operational during and after a disaster. They are critical infrastructure and a key component of community emergency response. Because of regulations and accreditation standards, U.S. hospitals are usually prepared for short term disruptions of lifelines, but long term outages can be a problem. As a result, the duration of a disruption is important to consider when developing contingency plans. Longer term disruptions of critical infrastructure can burden back-up lifelines. Because hospitals are part of larger systems, the consideration of risks associated with disruptions must extend beyond the individual facility and regard lifelines, transportation networks, supply chains, and other health care facilities (Menoni et al., 2000). The planning for these possible disruptions must be developed with the idea that they will be operationalized because if planning activities are simply undertaken to meet regulatory requirements, they are likely to be inadequate (McGlown, 2001).

Some hospital systems are bound to fail at some point. Even if we were able to implement all of the mitigation strategies we can imagine, the risk of a disaster will never be reduced to zero (Yoe, 2012). However, the inevitability of some disaster does not mean we should give up trying to reduce the probability of disruptive events or diminish their impact on health care operations. Rather, we should recognize that while these events occur infrequently, they are essentially guaranteed. Therefore, we need to be prepared. In addition to improving the robustness of our systems, we must also address redundancy and rapidity. That is to say, we need to establish backup systems and develop plans for restoring services as quickly as possible.

This review of the literature provides a broad overview of the manner in which hospitals address disruptive events and includes the role nonstructural systems play in the functionality of medical treatment facilities. It provides the national context for hospital preparedness; discusses how hospitals classify threats; identifies how hospitals characterize their capabilities and functionality; reviews the nature of past hospital evacuations; addresses how hospitals decide to evacuate; considers the importance of nonstructural systems in healthcare operations; and summaries key regulations that guide the planning and design of military medical treatment facilities with emphasis on the survivability of nonstructural systems.

Many of the terms used in this research proposal have definitions that are in dispute or remain unresolved in the literature. The terms and their meanings, within the context of this document, are included in the glossary, which is located in Appendix B.

2.1 National Context for Healthcare Preparedness

Current strategies and approaches to emergency management and homeland security in the US are heavily influenced by the terrorist attacks on 9/11, the anthrax attacks in 2001, and Hurricane Katrina in 2005. The largest terrorist attack in U.S. history led to a restructuring of the Federal Government with regard to homeland security activities and created an emphasis on improving coordinated, whole of government preparedness for disasters of national significance. Four years later, Hurricane Katrina added emphasis to the need for an all-hazards, capability-based approach to disasters that enabled a coordinated response by all levels of government and encouraged participation by the private and nongovernmental sectors. Additionally, the role individual citizens and their social networks can play to increase community resilience was recognized.

These events and the associated restructuring affected all aspects of emergency management practice, including health care emergency management. While hospitals have planned for emergencies and taken preparedness actions for decades, their approaches have been largely self-directed. The strategies and initiatives developed by the Federal Government are beginning to raise the awareness of a need for systematic approaches that produce predictable results and allow for adaptation in execution. The following subsections outline the relevant laws, strategies, and plans that affect healthcare and public health preparedness in the United States. Figure 2.1 is a graphic depiction of the national framework for homeland security with an emphasis on the healthcare and public health sector (modified from Department of Homeland Security, 2009; McGlown & Robinson, 2011).

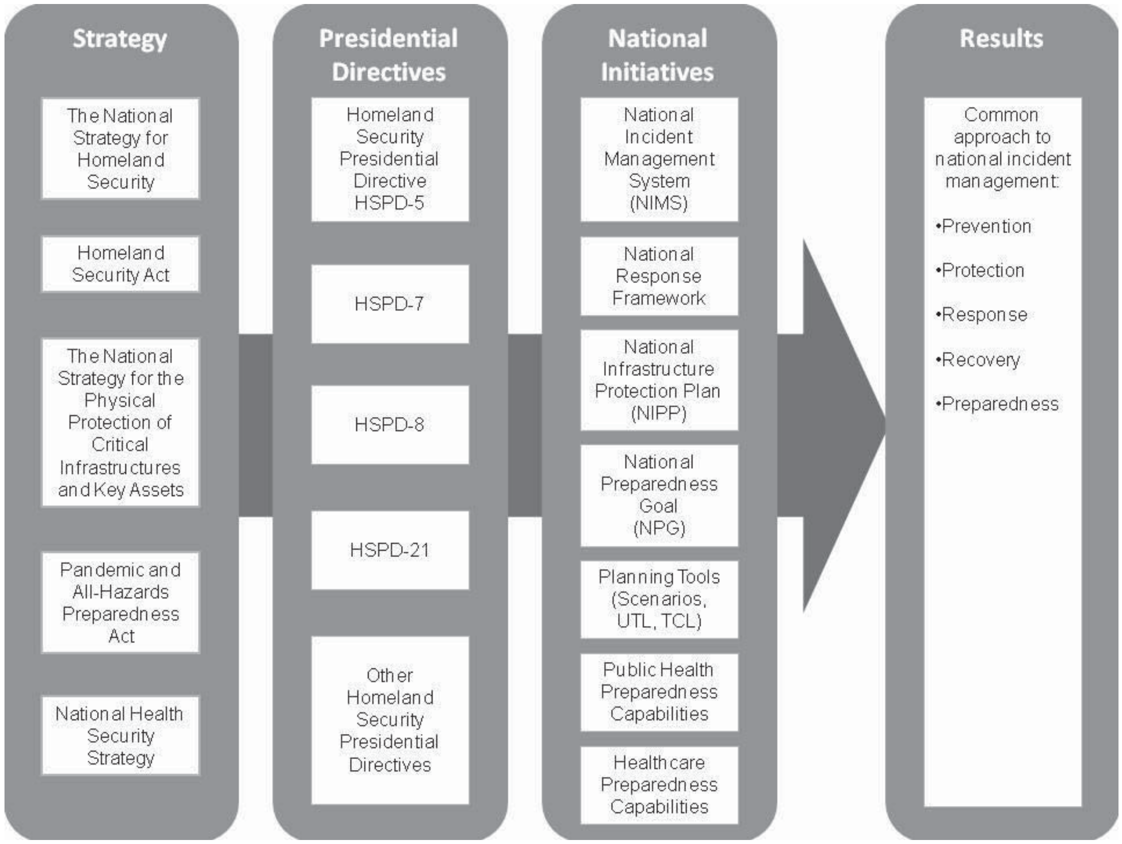

Figure 2.1: National Framework for Homeland Security and Public Health Preparedness

2.1.1 National Strategy for Homeland Security

The National Strategy for Homeland Security was initially issued in 2002, following the attacks on 9/11. It was updated in 2007. The strategy's aim is to unify the country's homeland security efforts against catastrophic events resulting from natural, technological, and human induced agents (Homeland Security Council, 2007). The four goals of the strategy are:

- Prevent and disrupt terrorist attacks;
- Protect the American people, our critical infrastructure, and key resources;

- Respond to and recover from incidents that do occur; and
- Continue to strengthen the foundation to ensure our long-term success.

The fourth goal involves a broad approach to combine the nation's resources and capabilities toward a culture of preparedness that involves comprehensive risk management, improved incident management, and employment of advances in science and technology.

2.1.2 Homeland Security Act

The Homeland Security Act of 2002 was one of two major laws passed following the attacks on 9/11 that fundamentally changed the manner in which the United States was structured to deal with major threats. The Act created the Department of Homeland Security, which was the largest reorganization of government agencies since the creation of the Department of Defense in 1947 (U.S. Congress, 2002). The Act also assigned the Department of Homeland Security responsibility for developing a comprehensive national plan for securing Critical Infrastructure and Key Resources (CIKR) and recommending measures to protect that CIKR.

2.1.3 Homeland Security Presidential Directive 5

Homeland Security Presidential Directive-5 (U.S. President, 2003a) directs all Federal agencies to adopt a national incident management system. The purpose of this effort is to improve multi-jurisdictional, cross-sector disaster management for domestic incidents.

2.1.4 Homeland Security Presidential Directive 7

Homeland Security Presidential Directive 7 (U.S. President, 2003b) establishes U.S. policy for enhancing protection of the Nation's CIKR and mandates a national plan to put that policy into action. The Secretary of the Department of Homeland Security is designated as the principal lead in CIKR protection efforts. To address the unique characteristics inherent in the different sectors, Federal Sector-Specific Agencies are assigned responsibility for CIKR sectors. The Department of Health and Human Services is the agency responsible for public health, healthcare, and food (other than meat, poultry, and egg products, which are under the purview of the Department of Agriculture) (Ibid.).

2.1.5 Homeland Security Presidential Directive 8

Homeland Security Presidential Directive 8 (U.S. President, 2003c) is a companion to HSPD-5. It directs the establishment of an all-hazards National Preparedness Goal to improve Federal assistance to State and local governments and improve local preparedness to major events.

2.1.6 Homeland Security Presidential Directive 21

Homeland Security Presidential Directive 21 (U.S. Department of Homeland Security, 2007) establishes a National Strategy for Public Health and Medical Preparedness for a catastrophic health event. The key principles of this strategy include coordination across all levels of government, engagement of the private and nongovernmental sectors, establishing regional approaches to health preparedness, and empowering communities to leverage their social networks for mitigation, preparedness, and response.

2.1.7 National Incident Management System

The National Incident Management System (NIMS) is a companion document to the National Response Framework. It is based upon five key components to effective incident management: preparedness, communications and information management, resource management, command and management, and ongoing management and maintenance (U.S. Department of Homeland Security, 2008a). The system describes a scalable, flexible management structure for emergency management in the United States. It is intended to create an interoperable system to enable coordinated emergency management activities across all levels of government and all sectors to improve domestic disaster response. The management structure is based on the Incident Command System, which can be modified to meet the needs of specific functional disciplines. The Hospital Incident Command System (HICS) is a NIMS-compliant structure for hospital incident management (California Emergency Medical Services Authority, 2006) that is widely adopted by hospitals in the U.S. and internationally.

2.1.8 National Response Framework

The National Response Framework (NRF) (U.S. Department of Homeland Security, 2008b) replaced the National Response Plan (U.S. Department of Homeland Security, 2006). It is intended to serve as a guide to an all-hazards response within the United States for all levels of government and private and nongovernmental organizations. In addition to the core document, the NRF consists of Emergency Support Function (ESF) Annexes, Support Annexes, Incident Annexes, and Partner Guides. The Emergency Support Functions provide a structure for organizing resources for the Federal response to a disaster. Public health and medical services are part of ESF #8. The Support Annexes provide guidance on the coordination and execution of common processes between and among the various organizational and individual actions that occur during a disaster response. These include critical infrastructure protection and recovery, public-sector coordination, and volunteer and donation management. The Incident Annexes apply to situations that require specialized response capabilities, such as biological, radiological, and catastrophic incidents.

2.1.9 National Infrastructure Protection Plan

Critical infrastructure is necessary to maintain the nation's security, health, and economy. Disruptions to such systems can negatively affect all aspects of our society, including government, businesses, and the lives of individual citizens. Interdependencies between infrastructures can result in cascading failures that impact multiple sectors and affect large geographic areas. The Homeland Security Act of 2002 defines critical infrastructure as,

> systems and assets, whether physical or virtual, so vital that the incapacity or destruction of such may have a debilitating impact on the security, economy, public health or safety, environment, or any combination of these matters, across any Federal, State, regional, territorial, or local jurisdiction (U.S. Department of Homeland Security, 2009, p. 7).

The National Infrastructure Protection Plan's overarching goal is to "build a safer, more secure, and more resilient America" (Ibid., p. 1). It seeks to accomplish this in two primary ways. First, it enhances the "protection of the Nation's CIKR to prevent, deter, neutralize, or mitigate the effects of deliberate efforts by terrorists to destroy, incapacitate, or exploit them" (Ibid., p. 9). Second, it strengthens "national preparedness, timely response, and rapid recovery in the event of an attack, natural disaster, or other emergency" (Ibid., p. 9). The plan builds on the principles of the President's National Strategy for Homeland Security and fulfills requirements in the Homeland Security Act of 2002 and Homeland Security Presidential Directive 7.

2.1.10 Healthcare and Public Health Sector-Specific Plan (Annex to the National Infrastructure Protection Plan)

Among the sectors that are identified as having CIKR is healthcare and public health. The mission of the Healthcare and Public Health Sector-Specific Plan (U.S. Department of Homeland Security, 2010) is to sustain the provision of health services and support emergency management for nationally significant hazards. Toward that end, the plan provides guidance on strategy implementation, risk evaluation, coordination among activities across the sector, and actions for the National Preparedness Goals' five mission areas: Prevention, Protection, Mitigation, Response, and Recovery (U.S. Department of Homeland Security, 2011) as shown in Figure 2.1.

Among the sector's four goals are service continuity, workforce protection, physical asset protection, and cybersecurity. Service continuity is the ability of the system to maintain the provision of healthcare during and after disasters or the disruption of essential support systems (e.g., utilities, pharmaceuticals, and supplies). Workforce protection is the protection of healthcare staff from hazards that can affect their health and safety. Physical asset protection is the mitigation of risks to the sector's physical assets, including facilities, equipment, and supplies. Cybersecurity is the mitigation of risks to the sector's information technology assets, whose disruption or loss can significantly impact the delivery of healthcare.

2.1.11 Pandemic and All-Hazards Preparedness Act

The Pandemic and All-Hazards Preparedness Act (PAHPA) was signed into law in 2006, amending the Public Health Service Act of 1944. The PAHPA's primary purposes are to improve public health security and implement an all-hazards approach to health preparedness and response activities (U.S. Congress, 2006). Among its directives is the establishment of a National Health Security Strategy and implementation plan that will accomplish six primary goals:

1. Integrate public health and medical capabilities with first responder systems.
2. Develop and maintain public health security capabilities, including biosurveillance, containment, risk communication, and distribution of countermeasures.
3. Increase medical preparedness, response, and surge capabilities.
4. Account for at-risk individuals, including children, pregnant women, the elderly, and those with special needs.
5. Improve coordination among all levels of government.
6. Plan for continuity of operations in the event of a public health emergency.

The PAHPA also specified that the strategy and implementation guidance be in accordance with the National Planning Guidance, the National Incident Management Strategy, and the National Response Plan.

2.1.12 National Health Security Strategy

The National Health Security Strategy (NHSS) identifies 50 essential capabilities organized in eight general areas "to minimize the health consequences associated with significant health incidents" (U.S. Department of Health and Human Services, 2009, cover letter). The capabilities are listed in Appendix C. The strategy's approach is in line with the National Preparedness Guidelines, which call for capabilities-based, all-hazards planning.

2.1.13 Public Health Preparedness Capabilities

The Public Health Preparedness Capabilities: National Standards for State and Local Planning (U.S. Department of Health and Human Services, 2011) identifies standards in public health preparedness planning to assist state and local planners in the development and sustainment of public health capabilities applicable to a wide range of disasters. The six domains and 15 capabilities created by the Centers for Disease Control and Prevention are listed in Appendix D.

2.1.14 Healthcare Preparedness Capabilities

The Healthcare Preparedness Capabilities: National Guidance for Healthcare System Preparedness (U.S. Department of Health and Human Services, 2012) creates standards in healthcare preparedness planning to assist state, local, medical coalition, and ESF #8 planners build and sustain healthcare capabilities in support of community disaster preparedness. The eight capabilities and their subordinate functions are listed in Appendix E.

2.1.15 Summary

Together, these laws, strategies, and plans direct an all-hazards, capabilities based approach to disaster management in the United States that emphasizes a cross-governmental, multi-sector approach to preparedness. The underlying belief is that by understanding our hazards/threats, vulnerabilities, and capabilities, we will be better prepared to prevent, respond to, and recover from major disasters and catastrophic events.

2.2 Classification of Threats

Within the emergency management and disaster science communities, hazards tend to be categorized as natural, technological, or human induced. The meanings of these terms are included in the glossary, which can be found in Appendix B. This taxonomy recognizes hazards that are naturally occurring, associated with human activity, but accidental, and associated with human activity, but purposeful. Hurricanes and earthquakes are natural hazards. Utility outages and chemical spills, assuming their cause is accidental, are technological hazards. Acts of terrorism are human induced hazards. This classification of hazards is the basis for our understanding of the risk posed by different threats. That knowledge is the foundation upon which we plan mitigation, preparedness, response, and recovery activities.

The exposure of people and their communities to these hazards can result in disruptions of varying levels of severity. Within the social sciences, there is a large body of literature addressing the levels of severity and how the resulting impacts should be classified (Fritz, 1961; Quarantelli, 2005). Generally, these events are characterized in increasing severity as emergencies, disasters, and catastrophes. Quarantelli (2005) notes that there are quantitative and qualitative differences between the three types of occurrences. The differences tend to be characterized in terms of time, space, impact, and ability and speed to respond or adapt.

Within the context of health care, The Joint Commission defines emergencies and disasters in the following manner (Landesman, 2005, p. 380),

> An emergency is an unexpected or sudden event that significantly disrupts the organization's ability to provide care, or the environment of care itself, or that results in a sudden, significantly changed or increased demand for the organization's services. Emergencies can be either human-made or natural (such as an electrical system failure or a tornado), or a combination of both, and they exist on a continuum of

severity. A disaster is a type of emergency that, due to its complexity, scope, or duration, threatens the organization's capabilities and requires outside assistance to sustain patient care, safety, or security functions.

Hospitals face a myriad of hazards that can hamper their operations, threaten the well being of their staff and patients, and degrade the facility's health care environment. The hazards that exist within the surrounding communities or regions likewise threaten the hospitals within those geographic boundaries.

In a hospital context, threats and disasters tend to be characterized as internal and external. External disasters are occasions that occur outside of a hospital, that affect a community, and may also affect the hospital. They frequently create a rapid and sustained increase in patient demand, commonly known as a surge. Internal disasters are specific to hospitals. They force staff to respond immediately to the threat, contain the effects of the impact, protect the lives and welfare of those affected, prepare for evacuation, and restore medical operations. Internal disasters include chemical spills, utility failures, and internal fires. Large external disasters, such as earthquakes and hurricanes, are likely to also create internal disasters within hospitals (Milsten, 2000). Table 2.1 lists several examples of internal and external threats that hospitals face (modified from Lewis & Aghababian, 1996).

While this section primarily relies on the characterization of hazards to classify the cause of disasters, it is important to understand that there is a difference between the hazard and the specific agent that generates the disruption. For example, hurricanes are recognized as a natural hazard, but the event driven agents that negatively impact communities are wind and water. High winds can damage property directly or carry debris that causes damage to property and death or injury to people. Similarly, heavy rain and storm surge can cause flooding that result in injury, death, and damage.

Table 2.1: External and Internal Threats

	Internal			External		
Hazards	Examples	Examples of Impacts		Examples	Examples of Impacts	
		Utility Failures	Impaired Safety		Lifeline Failures	Impaired Access
Natural		☑	☑	▪ Earthquake ▪ Flood ▪ Hurricane ▪ Tornado ▪ Wildfire	☑	☑
Technological	▪ Power Failure ▪ Water Loss ▪ Chemical Spill ▪ Radiation Exposure ▪ Fire ▪ Loss of Medical Gases ▪ Elevator Emergency	☑	☑	▪ Transportation Accident ▪ Chemical Accident ▪ Radiation Accident ▪ Lifeline Failures	☑	☑
Human Induced	▪ Bomb Threat ▪ Gunman ▪ Terrorism		☑	▪ Terrorism ▪ Mass Gathering	☑	☑

2.3 Hospital Capacity and Functionality

Hospitals maintain a range of medical services and a number of inpatient beds to support all, or a portion of, the community in which they exist. The clinical functions and the number of resources available in each facility are based upon the needs of the population being served. For the most part, these capabilities are established to meet routine requirements, but hospital staffs recognize that they must be ready to treat patients even if the number of those being treated exceeds what might be considered normal. Surges in the number of patients arriving at a hospital are known as mass casualty events. These are situations where the number of patients exceeds the usual capabilities of the facility and patients must be prioritized. Similarly, a reduction in the facility's capabilities brought about by a utility outage or other disruption in service may result in a mismatch between resources and patient demand. Understanding how hospitals characterize their functionality and capacity during normal operations and during increases in patient demand are important for understanding what actions need to be taken to ensure they are capable of meeting the needs of their patients during disasters.

"Healthcare capacity is usually measured in terms of resources or inputs in order to deal with the variety of the patient/service mix" (Bamford & Chatziaslan, 2009). Specific measures that have been utilized to assess capacity include patient categories, number of beds, operating room time slots, nursing workload, and appointment time slots. These measures demonstrate that patient status and acuity, the number of particular pieces of equipment, the number and usage periods of facility spaces, and the number of staff with particular specialties affect the ability of a hospital to care for and process patients. Due to differences in demand for certain functions, chokepoints can be created in the workflow of patient care. Key diagnostic tools, such as CT scanners and other radiological equipment, that are in high demand create the need for clinicians and patients to wait for their availability. The waiting period can increase the patient's length of stay, tie up a bed or treatment room, and, potentially, limit the ability of the hospital to accept more patients. This situation has been studied in emergency departments (Solberg, Asplin, Weinick & Magid, 2003; McCarthy, Aronsky & Kelen, 2006).

Emergency department overcrowding is worsened by higher levels of inpatient occupancy. If there are fewer beds to which to admit patients, the length of stay in an emergency department increases and the length of time an emergency department spends on ambulance diversion increases. Fundamentally, this is an issue of throughput. Patients who arrive at the emergency room and must be admitted need an inpatient bed. If none are available, the patient ties up a bed in the emergency department until they can be moved to a ward (McCarthy et al., 2006).

Solberg et al. (2003) evaluated an emergency department's capacity in terms of its ability "to provide timely care for the level of patient demand according to the adequacy of physical space, equipment, personnel, and the organizational system." These measures have also been identified as essential elements of surge capacity, which scholars refer to as staff (i.e., clinical, administrative, and support), stuff (i.e., equipment, medications, and supplies), and structure (i.e., physical and organizational) (Barbisch & Koenig, 2006; Kaji, Koenig & Bey, 2006; Kelen & McCarthy, 2006).

Surge capacity is the ability of a medical treatment facility to respond to a rapid and significant rise in patient demands (Kaji et al., 2006; McCarthy et al., 2006). To accomplish this, hospitals must be able to increase their number of available staff, gather additional supplies and equipment, find adequate treatment and bed space for an influx of patients, and implement an appropriate incident management system. The growth of the staff can be done through the unprompted return of staff members to the hospital, recall of staff members, activation of the Medical Reserve Corps, or arrival of medical volunteers (Auf der Heide, 1989; Auf der Heide, 1996; Milsten, 2000). Additional equipment and supplies can be taken from hospital contingency stocks, cross-leveled with other local hospitals, or acquired through the activation of the Strategic National Stockpile. To increase the hospital's treatment and bed capacity, additional beds can be added to inpatient rooms, beds can be placed in hallways, and administrative, support, or common spaces can be turned into patient care areas. The National Incident Management System mandates that emergency response organizations implement a federally compliant incident management system. Many hospitals in the U.S. use the Hospital Incident Command System (HICS).

Whether during normal or surge operations, capacity and functionality are not solely defined in terms of medical capabilities. The support systems necessary to facilitate medical care are equally important. A physician without power, water, medical gases, or medical equipment is less effective (or completely ineffective in many cases). As surge facilities are planned and designed, the need for utility and logistical support of treatment areas and beds must be considered. Contingency plans may be necessary in the intervening period before capital investments make these resources available.

2.4 Hospital Evacuations

Health care requires a safe environment in which skilled clinicians have access to all the equipment, medications, supplies and support systems necessary to heal the sick. When a disruption to any of these systems or elements occurs, it can negatively affect the quality of care being provided. If the scope or duration of the disruption is significant, it can create a situation in which the health care environment is no longer supportive of quality medical care. At that point, clinicians and administrators must reestablish an appropriate environment, which may necessitate an evacuation to alternate medical treatment facilities. In some cases, preemptive evacuations may be necessary if the threat to a health care facility is sufficient. While rare, hospital evacuations do occur. They are costly to the health care organization performing the evacuation, they put the continuity of patient care at risk, which can have implications for morbidity and mortality, and they are stressful for the medical providers and family members of patients.

Evacuations are characterized in a number of different ways, including external, internal, partial, complete, horizontal, and vertical. External evacuations involve moving building occupants outside of the facility. These events are typically classified as partial or complete. Partial evacuations typically include removing building occupants from a floor, a wing, a tower, or some other segment of a building. Complete evacuations involve the removal of all occupants from the entire facility. Internal evacuations entail the removal of occupants from hazardous situations without taking them from the building. Horizontal and vertical evacuations are forms of internal evacuations. In horizontal evacuations, people are moved within the floor to a safer area. Vertical evacuations take people from one floor to another (either up or down) to escape danger.

The following section describes hospital evacuations in terms of precipitating events, geography, and probability. It also provides several case studies of recent hospital evacuations to enhance our understanding of the complexities surrounding these events. The section concludes with discussions of evacuation triage, the process of moving patients out of a hospital, and the effects of evacuation on mortality and morbidity. This section is informed by several key surveys of hospital evacuations, which are listed in Table 2.2.

Table 2.2: Surveys of Medical Treatment Facility Evacuations

Study	Years	Number of Facilities	Types of Facilities
Bagaria, Heggie, Abrahams & Murray (2009)	1980-2008	69	Hospitals
Burgess, Blackmon, Brodkin & Robertson (1997)	1991-1995	101	Hospitals
Sternberg et al. (2004)	1971-1999	275	Hospitals
Vogt (1990)	1984-1987 1983-1987	34 63	Hospitals Nursing Homes

2.4.1 Causes of Hospital Evacuations

Two significant surveys of hospital evacuations provide insight into the causes of hospital evacuations (Sternberg et al, 2004; Bagaria et al., 2009). While there is some overlap in the time periods covered by their research, the two studies provide an overview of evacuations between 1971 and the late 2000s.

Sternberg et al. (2004) conducted a survey of hospitals in the United States that evacuated between 1971 and 1999 and identified 275 medical facilities that evacuated either partially or completely for a wide variety of reasons. The researchers divided the cause of hospital evacuations into 11 categories: internal fire (63), internal hazmat (49), hurricane (38), human threat (37), earthquake (26), external fire (16), flood (16), utility failure (13), external hazmat (10), weather (5), and miscellaneous (2). They determined that six named natural events accounted for 53 (19.3 percent) of the evacuations: Loma Prieta Earthquake (6), Hurricane Andrew (15), Northridge Earthquake (14), Hurricanes Bonnie and George (8), and Hurricane Floyd (10).

Sternberg and his colleagues (2004) found that internal fires and chemical spills were the most frequent causes of hospital evacuations, while earthquakes and hurricanes resulted in the largest number of patients evacuated. This indicates that large scale disasters, while rare, are likely to be more disruptive than smaller emergencies. Their scale can result in multiple facilities being affected simultaneously, which can hinder a community's disaster response. The potential for large scale disruptions adds emphasis to the need for robust and redundant nonstructural systems that can remain operational during a disaster, practiced hospital disaster plans, and regional mutual aid agreements to enable the long distance transfer of patients and staff.

Bagaria et al. (2009) conducted a survey of hospital evacuation case studies in published literature after 1980. They identified 21 articles that described 69 hospital evacuations in the United States and Canada. There is some overlap with the survey conducted by Sternberg et al. (2004), but this new survey adds information drawn from events that occurred during the first decade of the 21st Century, including from New Orleans in the aftermath of Hurricane Katrina.

Of the 69 hospitals studied, 45 were evacuated for natural disasters. Twenty-nine evacuations were associated with two earthquakes, which I suspect were Northridge and Loma Prieta. Interestingly, Sternberg et al. (2004) only attribute 20 hospital evacuations to those earthquakes. Another 15 evacuations associated with natural disasters were precipitated by hydro-meteorological events, including seven in advance of Hurricane Katrina. The remaining 24 hospitals evacuated for technological and human-induced hazards such as fires, a nuclear power accident, chemical spills, and utility failures not associated with a natural disaster. Among the hospitals that evacuated for natural hazards, the majority evacuated completely while most of those that evacuated partially were for technological and human-induced hazards.

2.4.2 Geography of Hospital Evacuations

There are geographic differences between threats and frequencies of evacuation. Across the nation, 29 states and the District of Columbia reported hospital evacuations between 1971 and 1999. The state with the most evacuations was California (77), followed by Florida (29), Texas (15), Louisiana (14), Massachusetts (12), New Jersey (10), South Carolina (10), and Washington (10). Coastal states tend to have a higher proportion of evacuations than other states (Sternberg et al., 2004). This trend continued after 2000 when major coastal storms such as Hurricanes Katrina, Rita, Gustav, Ike, Irene, and Sandy led to the evacuation of more than 100 hospitals (Gray et al., 2007; Andress, Downey & Schultz, 2007; Andress, 2009; Fink, 2012).

2.4.3 Probability of Hospital Evacuations

The complete evacuation of a hospital is a low probability, high consequence event. For it to be necessary, the disruption to the healthcare environment must be significant and of sufficient scope. Smaller disruptions may result in partial evacuations or the internal evacuation of patients within or between floors to avoid a threat, which are known as horizontal and vertical evacuation, respectively (Klein, 1996). While their data is admittedly incomplete, Sternberg and his colleagues (2004) developed a crude estimation that in the 1990s U.S. hospitals faced a 0.33 percent annual probability (average reported evacuations per year in the 1990s divided by the average annual number of hospitals) of evacuating for any hazard. When they separately considered data from the National Fire Protection Association (NFPA), the probability of any hospital experiencing a fire was 31 percent (for an average of one fire per year). Assuming that patients or staff had to horizontally or vertically evacuate, at a minimum, Sternberg et al. surmise that their survey of hospital evacuations was incomplete and the number of complete, partial, and internal evacuations in the United States from 1971 to 1999 was higher than 275, which means the probability a hospital will need to conduct some sort of evacuation in any given year is likely to be higher than 0.33 percent. However, the data also suggests that the likelihood of an external evacuation (complete or partial) is smaller than for an internal evacuation (horizontal or vertical). These estimates are based on averages of incomplete information and do not necessarily represent an accurate picture of the likelihood of a hospital evacuation. They do, however, indicate the difficulty of identifying such probabilities.

A survey of emergency hospitals in Washington State indicated that in a five year period in the early 1990s, 12 of 101 facilities partially evacuated because of hazardous materials incidents (Burgess et al., 1997). A follow-up survey to gain more information about the events attained details from ten hospitals, including one with two separate incidents. Seven of the eleven events resulted in the evacuation of the hospital's emergency department. Although the closures were typically of a short duration with a median of two hours and range of one to ten hours, they were disruptive to the hospital's operations and created a limitation on the community's emergency response capabilities. The rough probability of a hospital in Washington State experiencing a hazardous materials incident resulting in an evacuation was 2.5 percent, which is significantly higher than the probability Sternberg et al. (2004) found for all hazards of 0.33 percent.

Table 2.3 is a summary of hospital and hospice fires from 1980 to 2010 (Ahrens, 2012) and hospital statistics from the American Hospital Association (2011) with the estimated probability of hospital fires for the last three decades. There is a downward trend in the number of fires, number of hospitals, and the probability of a hospital fire. This suggests that the likelihood of an internal evacuation in a hospital may be decreasing as well. This analysis suffers from the same challenges faced by Sternberg et al. (2004) and Burgess et al. (1997).

Table 2.3: Estimated Probability of a Hospital Structure Fire in the U.S.

Decade	Average Number of Structures Fires in Hospitals[1]	Average Number of Hospitals	Probability of a Structure Fire in a Hospital
1980s	5,734	6,861	84%
1990s	2,092	6,314	33%
2000s	1,291	5,775	22%

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[1] Ahrens (2012) combined hospitals and hospices when aggregating fire data. A U.S. Fire Administration Report (2009) indicates that from 2004 to 2006, structure fires in hospices accounted for less than one percent of the 11,737 fires that occurred in medical facilities during that time period. Therefore, the average number of fires in this table is a reasonable approximation of the hospital fires in each decade.

2.4.4 Case Studies

Four case studies of events that precipitated or required hospital evacuations are described to provide context to these low probability occurrences. These case studies involve hurricanes and earthquakes that each resulted in the evacuation of multiple facilities. Three of the cases are in the United States and one is in New Zealand. The studies are provided in different levels of detail due to the availability of information, the number of sources, and how recently the events occurred.

2.4.4.1 Northridge Earthquake

On January 17, 1994, the Northridge Earthquake caused the evacuation of eight acute care hospitals in Los Angeles County, California. Two of the hospitals conducted partial evacuations while the remaining six evacuated completely. Six of the hospitals evacuated immediately following the earthquake due to extensive damage to nonstructural systems that hindered their ability to provide health care. Three of the hospitals lost electrical power and five experienced severe water damage from burst pipes and ruptured rooftop water tanks. These failures resulted in the functional loss of heating, ventilation, fire suppression, medical equipment, and supplies. The other two hospitals evacuated three days and 14 days after the event due to structural damage, which was not immediately identified. Of the six hospitals that completely evacuated, four were ultimately demolished (Schultz, Koenig & Lewis, 2003).

2.4.4.2 Hurricanes and the Gulf Coast

Between 2005 and 2009, the State of Louisiana was subjected to several hurricanes that led to the evacuation of hospitals, either in anticipation of the storms or as a result of their impacts. Hurricane Katrina, in 2005, created an unprecedented scale of disaster in New Orleans and set the tone for evacuation planning in the following years.

The Louisiana Hospital Association identified approximately 24 hospitals that evacuated because of Hurricane Katrina (Gray et al., 2007). Among those facilities were 11 hospitals that were surrounded by floodwater after the levees failed, trapping 1,749 patients and 7,600 staff, family members, and others. The report of 10,000 people stranded in New Orleans hospitals was widely circulated, but the breakdown of staff, family, and others was never published (Abelson & Feuer, 2005). Three years later, in 2008, there were between 67 and 73 hospital evacuations (85-86 percent before landfall) in southern Louisiana associated with Hurricane Gustav (Andress, 2009).

The death toll attributed to Hurricane Katrina is among the highest for a natural disaster in the United States. Of the 877 people who died in Louisiana due to Hurricane Katrina, and whose location of death or where they were found was recorded, 22 percent (n=195) were in hospitals and 12 percent (n=103) were in nursing homes. Among those, 70 people were inpatients in New Orleans hospitals between August 29, 2005 and September 2, 2005, in the immediate aftermath of the storm. The following week, another 57 victims were taken from local hospitals to the Disaster Mortuary Operational Response Team (DMORT) facility in Saint Gabriel, Louisiana. It is assumed their storm related deaths occurred in the medical facilities from which they were transported (Brunkard, Namulanda & Ratard, 2008).

The destruction wrought by Hurricane Katrina and the post-storm flooding was extensive and long lasting. Afterward, nine hospitals in New Orleans closed, including Charity Hospital (Campbell, 2007). Rebuilding is taking years. The replacement of the Veterans Affairs Medical Center was expected to open in the autumn of 2013, in a new cluster of hospitals in the Mid-City neighborhood, but construction delays pushed the estimated completion into early 2016 (U.S. Department of Veterans Affairs, 2013; Government Accountability Office, 2013).

2.4.4.3 Christchurch Earthquake

On 22 February 2011, a magnitude 6.3 earthquake occurred near Christchurch, New Zealand causing widespread damage to infrastructure, including lifelines, transportation networks, and healthcare systems. McIntosh, Jacques, Mitrani-Reiser, Giovinazzi, and Wilson (2012) studied the damage to six of the Canterbury Health System's 14 hospitals. All of the facilities lost some lifeline support: electricity (4), water (4), sewer (2), and telecommunications (4). Additionally, two of the hospitals experienced disruptions of their back-up power and a loss of centralized medical gas and suction. Two of the hospitals also received clean linen through alternate means when their laundry services were lost. Other nonstructural damage within the facilities consisted of the collapse of suspended ceilings and light fixtures, the failure of emergency lighting, and the rupture of water pipes and rooftop tanks.

2.4.4.4 Hurricane Sandy

On the night of 29 October 2012, Hurricane Sandy struck the East Coast at Brigantine, New Jersey. Because of its counterclockwise rotation, the storm surge and inundation was worst around New York City, Long Island, and Northern New Jersey (Blake, Kimberlain, Berg, Cangialosi & Beven, 2013). In anticipation of flooding associated with the storm, the mayor of New York City ordered a mandatory evacuation of Zone A but exempted hospitals and nursing homes. However, some hospitals were concerned enough about their ability to provide patient care that they evacuated anyway. New York Downtown Hospital evacuated 125 patients on 27 October (Lupkin, 2012). The Veterans Affairs Harbor Healthcare System evacuated 130 patients from its Manhattan facility on 28 October (Jordan, 2012). On the same day, the Hoboken University Medical Center evacuated its patients because of concerns the seawall would be inadequate to keep back the storm surge (Lupkin, 2012).

Hurricane Sandy pushed into the New York City metropolitan area around high tide on the night of Monday, 29 October. Flooding in Lower Manhattan, along the Hudson and East Rivers, and the southern edge of Brooklyn caused a significant power outage that forced hospitals, including New York University (NYU) Langone Medical Center, Bellevue Hospital, Coney Island Hospital, and Palisades Medical Center, in New Jersey, to rely on their emergency generators. On Monday night and Tuesday morning, the generators failed at NYU Langone, Bellevue, and Palisades prompting the evacuation of nearly 900 patients. Coney Island Hospital was also forced to evacuate after storm surge inundated the building's ground floor.

The following is a description of the evacuation experience at Bellevue Hospital based on staff reporting and interviews conducted by journalists. The experience serves as an example of the challenges faced by hospitals affected by Hurricane Sandy. At 9:00pm on Monday night, Bellevue Hospital, located at 462 First Avenue, was on back-up power. The oldest continually operating public hospital in the United States had 720 inpatients, including prisoners and psychiatric patients. By midnight, floodwaters in the medical facility's basement had damaged the fuel pumps that feed the hospital's generators, which are located on the 13th floor. Staff formed bucket brigades to carry diesel fuel up the 13 flights of stairs to keep the generators going. The next day, Tuesday, the shafts for all 32 elevators were flooded and the elevators ceased to work. Water faucets stopped working. Water had to be carried upstairs in buckets to flush toilets. Oxygen was being provided by bedside tanks rather than through the centrally piped system that normally supports patients. Food was beginning to run low. Doctors started talking about evacuating the hospital, and on Wednesday patients were carried down stairways to be transferred to other hospitals in the city. Among the facilities that accepted patients from Bellevue were Saint Luke's and Roosevelt Hospitals and Mount Sinai Hospital (Fink; 2012; Hartocollis & Bernstein, 2012; Rom, 2012).

2.4.5 Evacuation Triage

Evacuation triage entails determining which patients will be evacuated first. This is typically accomplished in one of two ways. The evacuation can either begin with the sickest patients or the healthiest patients. The first approach decreases the burden on staff and resources over the course of the evacuation, while the second course of action gets more people out of harm's way more rapidly.

When a threat is imminent, hospitals frequently attempt to evacuate the largest number of people as quickly as possible. This is done by evacuating the most able patients first and leaving those who need the greatest assistance to the end. Following the Northridge Earthquake, one of the six hospitals in Los Angeles County that evacuated immediately felt their facility was in danger of structural collapse. They chose to evacuate the healthiest patients first and moved 334 patients outside of the building in only two hours (Schultz et al., 2003).

When a threat is not perceived to be imminent, hospital staff tend to prefer evacuating the sickest patients first. These patients are the most labor and resource intensive. In most acute care hospitals, patients on ventilators and others in the intensive care unit would be in the first group to be evacuated. While this approach is slower, its benefits include reducing the demand on staff and resources over the course of the evacuation. This is important because available resources can be depleted quickly following a disaster.

2.4.6 Evacuation Process

Moving patients around a hospital is a necessary and normal part of health care operations. Inpatients must be taken for diagnostic tests, to surgery, and returned to their rooms. This movement is facilitated by a myriad of equipment from gurneys and wheelchairs to the elevators that carry the patients and equipment up and down within the building.

During an evacuation, the physical movement of patients out of a multi-story hospital can be especially challenging if primary and back-up electrical systems are not able to support elevators. Gurneys and wheelchairs can be used to move patients horizontally within floors or from the facility's ground floor to the outside. However, vertical evacuation between floors may require patients be carried down stairs using improvised solutions, including backboards, blankets, and sheets. When transporting critical patients, this process requires that essential medical equipment be transported with the patient. Additionally, patients on ventilators need to be manually ventilated while being evacuated and transferred to other facilities.

Of the six hospitals in Los Angeles County that evacuated immediately following the 1994 Northridge Earthquake, five were five stories or more tall, including one facility that was eight stories tall (Schultz et al., 2003). The inpatients on upper floors were vertically evacuated by stairway using improvised litters. Once outside, patients were staged in open spaces adjacent to the hospitals until transportation was available to take them to other medical facilities or they could be discharged.

When Hurricane Sandy struck Manhattan in October 2012, both NYU's Tisch Hospital and Bellevue Hospital had to be evacuated when both their primary and back-up electrical services failed. Due to the lack of power, the elevators in both hospitals were not available. Tisch Hospital is 18 stories tall, and Bellevue Hospital is 25 stories tall. As one example of the serious challenges faced by the hospital staffs, ten medical personnel from Tisch Hospital carried a critically ill, 200-pound man and over 60 pounds of equipment, including a vital sign monitor, infusion pump, and oxygen tank, which were all connected to the patient, on a transportation cot down 17 floors with only a flashlight to light the way (Penziner, 2012).

2.4.7 Patient Mortality and Morbidity

Patient mortality and morbidity is a constant concern when considering, planning for, and conducting a hospital evacuation. Patients are in a state of poor health. Some are critically ill and in need of intensive medical interventions. The continuity of health care for these patients can be the difference between life and death. The logistics of moving patients from one hospital to another while maintaining medical care are daunting.

Before Hurricane Katrina, some hospitals tried to identify other facilities where their patients could be transferred. However, the challenges associated with moving critically ill patients, some of whom were in traction or on mechanical ventilators, raised concerns about patient safety. Traffic congestion resulting from the New Orleans mayor's mandatory evacuation order, which exempted hospitals, and a shortage of ambulances, further complicated a difficult decision. Ultimately, many clinicians and administrators determined their patients were safer staying in the medical facilities in New Orleans (Gray et al., 2007).

While there is certainly evidence of deaths and injuries associated with evacuations from nursing homes and health care facilities (Zachria & Patel, 2006), it is possible that salient cases are distorting the perceived incidence of mortality and morbidity. Sternberg et al.'s (2004) study of 275 hospital evacuations in the U.S. from 1970 to 1999 found that 11 percent reported evacuation related casualties. Thirty facilities reported events that caused injuries and/or deaths (nine facilities reported at least one death). The incidents that created the largest number of deaths and injuries were earthquakes and internal fires. Vogt's (1990) study of 13 U.S. hospitals that evacuated between 1 January 1984 and 31 December 1987 and 63 U.S. nursing homes that evacuated between 1 October 1983 and 31 December 1987 found that only three of the nursing home evacuations reported fatalities. None of the hospitals reported deaths or injuries. Castle and Engberg (2011) determined that mortality is increased for evacuated nursing home residents when they compared physical and mental health outcomes of Louisiana nursing home residents who evacuated following Hurricane Katrina (n=684) and other nursing home residents in Southern states (n=46,035). Their findings showed that those residents who evacuated were more likely to die during the study period and more likely to have pressure ulcers, but they were less likely to fall or have behavioral health issues. Hyer and Dosa (2012) studied nursing homes that either evacuated or sheltered-in-place during Hurricanes Katrina, Rita, Gustav, and Ike. They determined that with the exception of Hurricane Ike, increased mortality and morbidity following the events could be attributed to evacuations. During the recent hospital evacuations for Hurricane Sandy in New York and New Jersey, there were no reported deaths (Fink, 2012). While these examples show there is some evidence that evacuations can negatively affect especially vulnerable populations, it is not clear that they are uniformly detrimental to the general hospitalized population. What is commonly understood is that evacuating patients with adequate resources in a controlled environment is preferable to evacuating without power or other vital utilities when resources are dwindling and disaster related demands on staff are increased.

2.5 Evacuation Decision Making

The decision to evacuate a hospital or shelter-in-place is fraught with complexity and uncertainty. The decision can be made by many different people. Horizontal and vertical evacuations in the face of an immediate threat might be made by clinical staff, fire officials, or other first responders (Milsten, 2000; Vogt, 1990). For complete evacuations before slow onset events, hospital owners, administrators, and government officials frequently make the decision. In complete evacuations, hospital administrators generally prefer an order from a government official that tends to make additional resources available, removes some regulatory restrictions, and may provide post-event financial assistance or reimbursement. Regardless of who makes the evacuation decision, it must be communicated throughout the organization to enable the coordination of staff and resources and avoid the confusion that can follow conflicting decisions.

The decision to shelter-in-place or evacuate a hospital is fundamentally about whether the staff and the facility can continue to provide an acceptable standard of care for patients. While the default course of action when considering whether or not to evacuate a hospital is to shelter-in-place (Government Accountability Office, 2006), there are many factors that influence that decision. Prior to an event, hospital clinical and administrative staff must consider the event's nature and anticipate its impact (Agency for Healthcare for Research and Quality, 2010). Factors included in the nature of the event are expected arrival time, magnitude, area of impact, and duration. When considering the impact of the event, decision makers must imagine the effects of the disaster on the hospital and community beforehand. McGlown (2001) determined that among 32 variables considered to be important in making a hospital evacuation decision; at least nine were related to the ability of nonstructural systems to support health care. These include the loss of power, water, communications, and supplies. Each hospital consists of structural and nonstructural components that create the health care environment and enable clinicians to heal the sick. Modern health care is dependent on reliable utilities, communications, logistics, and transportation networks.

Research and experience demonstrate the challenges associated with hospital evacuations and why we are inclined to avoid them. However, history also shows that evacuations are sometimes necessary. For this reason, it is important that we understand the decision making process and prepare for the potential necessity of evacuating our health care facilities.

2.6 Influence of Nonstructural Systems on Hospital Functionality

Medical treatment facilities consist of structural and nonstructural systems. Structural components are those elements of the building that are responsible for keeping it standing, including the foundation, columns, load bearing walls, and floors. Nonstructural components make up the systems that are integral and necessary for the operation of the hospital but which are not part of the structure. Essentially, if it is not load bearing, it is a nonstructural component. These include building utility systems, architectural elements, and building contents (Federal Emergency Management Agency, 2005). The systems and some of their elements are listed in Table 2.4.

Table 2.4: Nonstructural Systems

Nonstructural Systems and Components	**Nonstructural Elements**
Building Utility Systems	Mechanical and electrical equipment and distribution systems. Water, gas, electric, and sewerage piping and conduit. Fire suppression systems. Elevators and escalators. Heating, ventilation, and air conditioning systems. Medical gas systems. Central vacuum systems. Mass notification systems. Telecommunications systems.
Architectural Elements	Partitions and ceilings. Windows. Doors. Lighting. Interior or exterior ornamentation. Exterior panels, veneer, and parapets.

Table 2.4 continued

Building Contents	Computer and communications equipment. Cabinets and shelving for record and supply storage. Food service and laundry facilities equipment. Medical equipment and supplies. Medical gas cylinders. Library stacks. Furniture. Movable partitions. Lockers. Vending machines.

Nonstructural systems are essential for maintaining an appropriate environment in hospitals and providing an appropriate level of health care. Electricity powers building controls, which are responsible for temperature and humidity throughout the facility. Life support, diagnostic, and monitoring equipment is dependent on power, too. Fire suppression and steam sterilization systems cannot function without water. Because of their importance in supporting health care operations, the vulnerabilities inherent in nonstructural systems must be understood and mitigated. We need to identify methods for reducing the probability they will fail, reducing the consequences of their disruption, and reducing the time necessary to restore their functionality (Bruneau et al., 2003). The following sections describe the role various nonstructural systems serve in hospitals, identify some of their vulnerabilities, and describe the role their disruption may play in evacuation decision making.

2.6.1 Electricity

Hospitals need electricity to function. It is required to operate diagnostic equipment (e.g., radiology and laboratory equipment), life support equipment (e.g., ventilators, dialysis machines, and incubators), essential support equipment (e.g., sterilizers, and blood bank refrigerators and freezers), and building controls and motors, which are necessary to maintain appropriate temperature and humidity. Building controls are also necessary for maintaining negative pressure in isolation and decontamination rooms. Without electricity, the time a hospital can continue to function is measured in hours. Ventilators have battery packs that can last for 2-3 hours, but their associated suction devices generally lack battery back-ups (Agency for Healthcare Research and Quality, 2010). While hospitals are required to have emergency power, there is variability in terms of their capabilities and vulnerabilities. Hospital staff should know the capacity of their back-up power source, which outlets are part of the essential electrical system and which are for nonessential loads, the capacity of their onsite fuel storage, whether the fuel storage tanks feed the generators directly, and whether any hazards would prevent or hinder refueling (i.e., whether underground fuel tanks can be refilled during a flood).

The impact of the loss of the primary and emergency electrical systems at Bellevue Hospital during Hurricane Sandy was described among the case studies earlier in this chapter. While the hospital's generators were safe on the 13th floor, the fuel pumps that feed those generators were located in the building's basement, which is a common location for boilers, electrical switches, and fuel pumps. However, Bellevue is located near the East River in New York City's Hurricane Evacuation Zone B, and storm surge from the hurricane flooded the hospital's basement, damaged the fuel pumps, and caused the back-up power system to fail. The staff fought for days to keep the back-up generators working, including a 13-story bucket brigade of hospital staff and New York National Guardsmen ferrying fuel to the generators (Hartocollis et al., 2012), before evacuating patients on Wednesday, 31 October.

In addition to its role in supporting health care, electricity is necessary for the conduct and preservation of research. In 2005, Hurricane Katrina and the resulting loss of power at Tulane and Louisiana State University Health Sciences Center threatened frozen biological samples collected for decades (Guterman, 2005). More recently, when New York University Langone Medical Center evacuated because of flooding and power loss precipitated by Hurricane Sandy, research centers in the building were also affected. A mouse breeding lab in the facility's sub-basement flooded, killing thousands of laboratory mice, and the loss of electricity led to the thawing and loss of hundreds of biological samples (Akst, 2012).

2.6.2 Water

The loss of water in a hospital can quickly lead to the need for evacuation if the service is not restored. In addition to drinking and sanitation, water is necessary for fire suppression, sterilization, patient decontamination, heating, and cooling. Hospital staff members should be aware of the existence of secondary water lines, storage tanks, and wells serving as back-up sources of water. As an example of the importance of water, the safety officer from a major hospital in New York acknowledged that they lack a back-up source of water. Although they have pallets of bottled water on site, they do not have a back-up supply to support their heating, ventilation, and air conditioning system. As a result, a loss of municipal water would force them to evacuate the hospital within 24 hours.

In January 2014, a chemical spill in the Elk River contaminated the water supply of nine counties in West Virginia. The state directed residents and businesses in the affected area to avoid using their tap water for drinking, cooking, and washing. People who may have been exposed to the contaminated water were directed to seek medical attention. Hospitals in the affected counties were challenged by the water outage and an increase in emergency room visits by people concerned about exposure. To deal with the loss of their primary water service, medical treatment facilities stockpiled bottled water, instituted water conservation measures, contracted linen cleaning and instrument sterilization, and reduced or closed non-emergency care (Charleston Gazette, 2014; Kersey, 2014; Stapleton & Watkins, 2014).

At the end of January 2014, during a period of particularly cold weather, a water pipe broke on the sixth floor of the inpatient tower at Brigham and Women's Hospital in Boston. The resulting damage led the facility to internally evacuate 30 patients, cancel elective surgeries, and divert ambulances from the emergency department for eight hours (Abel, 2014). Such a small failure in a single component of a major building utility system caused a significant disruption to the hospital and resulted in lost revenue from potential patients diverted to other facilities. While not documented in this case, health care could have been delayed or treatment compromised, also.

2.6.3 Steam

Some hospitals rely on steam for heat. A loss of water at the steam plant, the inability of the plant to produce steam, or the inability of distribution pipes to deliver steam to the hospital could result in a loss of heat. An extended loss of steam during the winter months may give a hospital 1-2 days to evacuate before health and comfort are compromised (Milsten, 2000; Agency for Healthcare Quality and Research, 2010).

2.6.4 Natural Gas

Some hospitals use natural gas to generate heat and/or hot water. Much like with the loss of steam for heat, an extended loss of natural gas, particularly during winter months, could necessitate evacuation within 1-2 days (Agency for Healthcare Research and Quality, 2010). Hospital staff should know how many natural gas lines serve the hospital and how the loss of some or all lines would affect operations.

2.6.5 Real Property Installed Equipment

Real property installed equipment are those major pieces of equipment that are an integral part of the facility, such as heating systems. These systems are composed of numerous components, which require regular maintenance and must be replaced from time to time. Their loss can affect the functionality of a hospital. Many large buildings, including hospitals, rely on boilers to generate hot water, while some also use them to provide heat. Chillers are commonly used for air conditioning. Air handling units provide ventilation, the delivery of heated or cooled air, and the appropriate number of air changes per hour to occupied spaces. Because of their size and cost, back-ups of these equipment items are rare (Agency for Healthcare Research and Quality, 2010). Their role in maintaining appropriate temperature and humidity means their loss or disruption could require an evacuation, depending upon weather conditions.

Another example of real property installed equipment is elevators. They serve an essential role in multi-story hospitals. Elevators enable the vertical movement of patients, staff, equipment, and supplies for patient care and health care operations. Without functioning elevators, evacuations can be made more complicated and resource intensive. Bellevue Hospital experienced this specific challenge in October

2012 when storm surge from Hurricane Sandy caused the loss of primary and back-up power. Without power, the elevators would not function and patients had to be carried down flights of stairs to be evacuated. However, two patients were too sick to be carried and had to wait several days to be evacuated when elevator service was restored to the hospital (Newman, 2013).

While elevators are reliant on electricity for normal operations, the failure of components, such as motors and controls, can disrupt an elevator's functioning, also. Hospitals tend to have numerous elevators for passenger and service functions, which provide operational redundancy. However, a widespread power outage can affect all of a hospital's elevators simultaneously.

2.6.6 Medical Equipment

A good deal of medical equipment is dependent on electricity for its operation. While some medical equipment necessary for life support has backup battery packs, others do not. For example, ventilators frequently have battery packs that will last 2-3 hours. Hospital staff should be aware of the built-in backup power capabilities of life support equipment, the number of those items they have on-hand, and the needs of their patients to help them prioritize the evacuation order of patients in the event of a complete power outage.

Additionally, depending on the capabilities of the emergency power system, some pieces of equipment may not be supported by the back-up system. It is possible that during a disruption of the primary electrical service some pieces of treatment, diagnostic, support, or administrative equipment may not be functional. This can have unanticipated consequences if the staff is not familiar with the location and capacity of emergency electrical outlets.

2.6.7 Medical Gas and Central Vacuum

Medical gas and central vacuum systems are important to total patient care. Medical gas systems commonly deliver oxygen, nitrogen, nitrous oxide, medical air, carbon dioxide, natural gas, ethylene oxide, hydrogen, helium, and acetylene (Klein, 1996). Some of these gases are flammable and some are poisonous. These dangers drive stringent requirements for the installation, maintenance, and operation of these systems. Vacuum systems are also at risk of fire and explosions.

Medical gases are delivered in two primary ways: bulk and cylinder systems. Bulk medical gas systems require a primary source of supply and a reserve supply consisting of cylinders with at least one average day of supply. Cylinder systems, on the other hand, may or may not have a reserve supply. Additionally, compressors are frequently used to deliver medical air rather than cylinders of compressed air.

Medical gases are a consumable good. Once used, bulk and cylinder supplies must be replaced through the supply chain. Disruptions to logistics or transportation systems can hinder a hospitals ability to replace medical gases, which may negatively affect the provision of supplemental oxygen to patients, anesthesia, "power" for surgical instruments, support for surgical and medical procedures, and waste anesthesia gas disposal.

2.6.8 Information Technology

Contemporary health care is increasingly reliant on information technology for daily operations. Automated systems are used for laboratory and pharmacy ordering, automated dispensing units rely on an information technology backbone, and many hospitals are transitioning to electronic medical records. Within the information management community, the emphasis on back-ups tends to be a focus on protecting data rather than establishing redundant or alternate systems to maintain operations. Many hospitals lack practiced manual processes to continue operations when information technology systems are disrupted. This can result in delays or the cessation of health care delivery.

The transition to electronic medical records can be particularly problematic during an evacuation. Some systems can quickly generate discharge summaries while others cannot. Regardless, the process is time consuming, depends on electricity, and requires logistics support for adequate paper, printer ink, and health record folders or envelopes. This is primarily a problem when patients are transferred outside of the hospital's system or network. If patients are evacuated to another facility within the healthcare system, their electronic records may be accessible by the receiving facility, which could make one step in the evacuation process easier (Abir, Mostashari, Atwal & Lurie, 2012).

2.6.9 Telecommunications

There are myriad types of telecommunications devices used by hospitals. Landline, mobile, and Voice Over Internet Protocol (VOIP) telephones are common, as are two-way radios. However, some of these technologies are subject to disruption or failure during disaster events (Milsten, 2000). Landline service can be lost if telephone switches fail, backup generators fail, or fuel for these generators runs out. Digital telephones cease to work without electricity. Mobile phone service can be disrupted by the functional loss of cellular towers or the loss of the data systems that manage call routing and billing. Because of the geographic dispersion of account data, a disaster in one location can disrupt service to mobile phone users in another area (Agency for Healthcare Research and Quality, 2010). VOIP telephones are dependent on electricity and Internet access. If either is lost, VOIP phones will not send or receive calls. Two-way radios are reliable as long as their batteries last, but there have been well documented issues with interoperability between emergency responders using different systems. Awareness of this problem has led to improvement in interoperability. To overcome telecommunications outages during disasters, some hospitals and long term care facilities have utilized ham radio operators to relay messages within and beyond the disaster area (Milsten, 2000; Carlson, 2005; Disaster Research Center, 2012; Kendra et al., 2012). Satellite telephones can also be useful, but they are limited by the ability of people within the disaster area to receive phone calls.

2.6.10 Logistics and Transportation

Many hospitals have transitioned to just-in-time logistics, which reduces the volume of on-hand medications and supplies they need to stock locally. During normal operations, this process is efficient and significantly reduces waste and loss through expiration of products. However, during disaster events, when transportation networks are disrupted and demand for resupply increases, just-in-time delivery may be a liability. Hospitals may run low or completely out of critical pharmaceuticals and supplies without the ability to replace them quickly. Milsten (2000) recommends keeping seven days of critical supplies on-hand. The disruption of transportation networks not only affects the delivery of supplies but also the removal of general and medical waste. The storage capacity for these waste streams is limited within a hospital, so disruptions to their pick-up and removal can create a significant challenge.

In addition to the supplies necessary for medical care, hospitals are reliant on replacement parts for non-medical equipment, food stocks, paper products for hygiene, and many other replaceable or disposable items necessary for the full functioning of an acute care facility. The hospital faces the same challenges with these items that it has with pharmaceuticals and medical supplies. If sufficient supplies are not on-hand before a disaster event, it may be difficult to get resupplied in the immediate aftermath.

In the event of an evacuation, the ability to move patients, equipment, supplies, and medical records is dependent on the availability of vehicles, transportation routes, and facilities capable of accepting evacuated patients. Hospitals rarely have fleets of organizationally controlled or owned ambulances large enough to accommodate a complete evacuation. As a result, they must rely on contracted or borrowed (through mutual aid agreements) ambulances, which are likely to be under increased demand during a large-scale or community-wide disaster that affects multiple hospitals. In preparation for Hurricane Sandy, FEMA mobilized 350 ambulances and crews from outside the affected area to provide medical transport (Byrne, 2013). The evacuation of several hospitals would have taken longer had those resources not be available.

Large disasters and mass evacuations can also affect the availability of transportation routes. Before slow onset events, roadways can be congested with traffic from evacuees. In the immediate aftermath of a disaster, roads can be congested with those seeking information, and transportation infrastructure can be damaged or inaccessible. The uncertainty surrounding the impacts of slow onset events leaves all hospitals in the forecasted area of impact with the decision to shelter-in-place or evacuate. Even if they decide to shelter-in-place, they may be unwilling to accept patients from hospitals choosing to evacuate. Depending on the size of the event, it is possible that hospitals that are willing to accept patients may be hours away from those facilities that are evacuating. In those cases, the time necessary to travel back-and-forth over long distances with a limited number of patients in each ambulance can be extraordinary.

Prior to the landfall of Hurricane Katrina, some hospitals considered evacuating their patients, but they found it difficult to find an adequate number of ambulances and the mass evacuation of New Orleans created extremely heavy traffic congestion, which would have significantly slowed the evacuation of patients and tied up ambulances for hours. Additionally, the scale of the hurricane left inland hospitals uncertain of how they would be affected by the storm and unwilling to accept more patients (Gray et al., 2007). In its 2011 evacuation operations outline, the City of Port Arthur, Texas noted the importance of being able to mandate the evacuation of medical facilities, nursing homes, and hospitals before the general population to mitigate the effects of traffic congestion (Texas Department of Public Safety, 2011).

A recent example of how disruptions to the transportation network can negatively affect hospitals occurred in Colorado. In September 2013, record flooding caused widespread damage to communities and infrastructure. Two major roadways into Estes Park, a community on the southern edge of the Rocky Mountain National Park, were washed away leaving only one road with access to surrounding communities (Colorado Department of Transportation, 2013). The damage left the 25-bed Estes Park Medical Center with significant concerns about access for supplies and staffing. As a result, the hospital canceled all routine care, but maintained urgent and emergent services with limited staff (Estes Park Medical Center, 2013). Because the small medical treatment facility lacks an intensive care unit, high acuity patients must be transported to more capable hospitals in the area. The loss of more direct routes means that hospitals that used to be one hour away are now three or four hours away (Whitney, 2013). The additional transport time limits the daily capacity of ground ambulances, which may affect the mortality and morbidity of some patients. The greater ground transport time may also put greater strain on limited air ambulance resources. This increase in demand comes with a financial cost.

Such large scale events can also affect the supply chain. Severe flooding in Thailand in latter half of 2011 killed hundreds of people, hurt the country's economy, and had a global impact. More than 40 percent of the world's hard drives were made in Thailand before the flooding (Fuller, 2012). The disruption of that manufacturing base affected the availability of computers and external hard drives around the world, which resulted in fewer products on the shelves and increased prices for those that were available. Figure 2.2 shows a photo taken by the author at a computer store in Wilmington, Delaware in the winter of 2012. Similar disruptions could affect medical equipment, supplies, pharmaceuticals, or other key items that hospitals and their dependent systems need to maintain their operations.

Figure 2.2: Widespread Supply Chain Disruptions from Flooding in Thailand

2.6.11 Physical Security

Maintaining physical security of a hospital, its equipment, and transportation assets during a disaster can be challenging. Automated systems typically employed to monitor the building and campus may be disrupted resulting in the need for additional security personnel to guard building entrances or patrol hospital grounds. Without power, wireless systems for property accountability will not function, which may increase the likelihood of theft. Despite the existence of contracts for additional security, austere conditions, security concerns, and increased demand during disaster events may delay the arrival of those security personnel. Additionally, local police and National Guard service members may have other priorities that limit their ability to assist local hospitals in a timely manner (Agency for Healthcare Research and Quality, 2010).

2.6.12 Architectural Elements

Architectural elements consist of nonstructural building components that define space and provide ornamentation, including wall partitions, ceilings, doors, windows, and overhead lighting. There is widespread evidence of earthquake induced damage to suspended ceilings, lights, windows, and doors. Collapsed ceilings and broken windows can injure building occupants. This type of damage, along with bent door frames (Milsten, 2000), can also block evacuation routes. In addition, high winds can break windows, damage exterior architectural elements, and create windblown debris that can injure people and damage property.

On 22 May 2011 an EF5 tornado struck Saint John's Hospital in Joplin, Missouri. There were 183 patients and 117 staff members present at the time of the storm. The level of devastation was tremendous. Nearly all of the facility's windows were blown in, all the utility systems were lost, and the medical gas system was rendered inoperable. The collapse of the ceiling and overhead lights blocked access to the Intensive Care Unit. Ultimately, it took two hours to evacuate all of the patients from the hospital (Farnen & Meuschke, 2013).

2.6.13 Physical Space

The role that physical space and the placement of support systems (particularly utilities) play in the provision of health care during disruptions receives insufficient attention. Adequate and appropriate space is a factor in both surge capacity and the ability to evacuate patients in a timely manner.

Accommodating additional patients, the equipment and supplies to support them, and added staff is dependent on space. While common areas and hallways may be converted into patient care areas during surge events, these spaces typically have insufficient utility support for monitoring and medical equipment, limited hygiene facilities, limited controls for general or task lighting, and a lack of auditory and visual privacy.

Physical space is also important when considering evacuations. While the width of corridors and stairwells may meet NFPA and International Building Code (IBC) requirements, designers must also consider whether those widths can accommodate a patient, life saving equipment, and staff evacuating without electricity during a disaster. That planning must also consider the likelihood of other staff members moving in the opposite direction to retrieve additional patients (Penziner, 2012).

2.7 Current Practices in Military Medical Facility Planning and Design

This section briefly describes current practices in the planning and design of military medical facilities. It also identifies some of the key codes and regulations that apply to hospital design. It is not comprehensive. There are scores of documents that provide guidance on the design and construction of medical treatment facilities. The documents summarized here are particularly relevant to military hospital functionality and survivability.

2.7.1 Planning

The Department of Defense uses the Military Health System (MHS) Capital Investment Decision Model (CIDM) to prioritize medical construction projects to support strategic capital investment budget decisions. To have a project considered for funding, the Service must submit a Capital Investment Proposal consisting of project planning assumptions, space and equipment requirements, an economic analysis, a brief project narrative, a budgetary document that summarizes the project's major requirements, and, if applicable, justification that the facility is mission essential. Mission essential, in this context, means the facility is necessary to installation (community) operations and should be designed and constructed to be more reliable and durable than a facility without the designation. The justification must identify what functions are to be maintained and under what conditions (U.S. Department of Defense, 2012, Nov. 1).

A planning charrette is typically conducted to develop the project and complete the budgetary document that describes the project site, scope, and estimated cost, which is necessary to justify military construction projects to Congress. As part of the process, a multi-day workshop is held where key stakeholders from the hospital, community, and project management team come together to define the broad parameters of the project. Among the activities specifically addressed are seismic, flood hazard (emphasis on flood plains and wetlands), anti-terrorism/force protection, and physical security requirements (U.S. Army Corps of Engineers, 2003, Nov. 6).

Once the project gains support and is prioritized by the Defense Health Agency, it continues to be developed and the documentation refined. Prior to receiving the initial design authorization, the using Service updates the budgetary document; develops the room-by-room list of equipment; gathers site information regarding utilities, environmental considerations, existing conditions, transportation access, and community architectural design guidelines; develops a contingency mode concept of operations to address the operational accommodation of increased health care demands associated with contingency operations and whose impacts will be included among the design requirements; updates the strategic concept of operations (a key element of the project planning assumptions); and gets site approval from the installation (U.S. Department of Defense, 2012, Nov. 1).

2.7.2 Design

Design is a multi-step process of developing the scope and cost of a construction project. It begins with design authorization. After the selection of an architect/engineer (A/E), a design charrette is commonly held. It is a short (three day to two weeks), intensive process by which project stakeholders (designers, hospital staff, and community representatives) come together to define project requirements and gather information. It is more detailed than the planning charrette but generally follows the same process. In addition to updating the project requirements, the team generates single line sketches of the site and floor plans. The Engineering and Construction Bulletin (U.S. Army Corps of Engineers, 2002, Sep. 6) that provides guidance for conducting the design charrette does not provide any additional information about assessing hazards than the instructions for the planning charrette.

Design continues through a process of development, review, and validation. Concept design narratives are required to summarize key features of the building and its systems. The disaster related aspects include contingency and mobilization features, post-earthquake operation requirements, emergency electrical systems, fire protection, life safety, physical security, and anti-terrorism/force protection. The design analysis and development culminates in a complete design package. Among the final documents are the drawings, design narrative, specifications, equipment lists, and cost estimate (U.S. Department of Defense, 2012, Nov. 1).

2.7.3 Building Codes

The Department of Defense adopted 2012 International Building Code (IBC) for its projects. The Department relies on Unified Facility Criteria to supplement those requirements and provide Department specific guidance. Below are several key documents relevant to military hospital design and construction.

2.7.3.1 General Building Requirements

All Department of Defense facilities must comply with Unified Facilities Criteria 1-200-01 (2013, Sep. 1), *General Building Requirements*, which identifies applicable building codes and standards.

2.7.3.2 Structural and Seismic Design

Unified Facility Criteria 3-301-01 (2013, Jun. 1) includes modifications to the seismic engineering requirements included in the International Building Code specific to the needs to the U.S. Department of Defense. The regulation specifies factors to be used in calculating seismic, wind, snow, ice, and flood loads for structural engineering based on five categories of risk (similar to the occupancy categories in the IBC). The factors are applied to location-based loads listed in the criteria. Institutional facilities, like hospitals, with emergency or surgical capabilities are Risk (Occupancy) Category IV. Institutional facilities without emergency or surgical capabilities and an occupant load of at least 50 people are Risk (Occupancy) Category III. Public utilities are primarily Risk (Occupancy) Category III, also. Facilities involved in emergency response such as fire stations, police stations, emergency shelters, and emergency power facilities are Risk (Occupancy) Category IV.

Unified Facility Criteria 4-510-01 (2012, Nov. 1) defines the occupancy category seismic performance levels as: Occupancy Category II "life safety," Occupancy Category III "safe egress," and Occupancy Category IV "immediate occupancy." The regulation defines immediate occupancy as (Ibid., para. 6-3.3),

> a higher level of seismic resistance capability than the SE [safe egress] level and should be applied to structures required for post-earthquake recovery operations following the design-level earthquake. The risk of life-threatening injury as a result of structural damage is very low, and although some structural damage may occur, repairs would generally not be required prior to resuming occupancy. All critical utilities and equipment shall be isolated, supported, or both, so the functionality can be maintained following the design-level earthquake. Provisions are required for temporary emergency connection or augmentation of potable water, sanitary sewers, and fuel. In existing facilities where upgrade of all portions of the facility is economically impractical, upgrade may be restricted to the more Critical Care Areas and systems as identified in the program authority document.

2.7.3.3 Anti-terrorism/Force Protection Standards

Unified Facility Criteria Series 4 includes several regulations that detail security engineering requirements related to anti-terrorism and force protection that apply to all Department of Defense facilities (U.S. Department of Defense, 2013, Oct. 1; Department of Defense, 2008, Sep. 11). These criteria establish guidance for maximizing the distance between facilities and threats, minimizing flying debris and airborne contaminants, preventing building collapse, and providing mass notification during emergencies. Since the bombing of the Alfred P. Murrah Federal Building in Oklahoma City and the attacks on 11 September 2001, anti-terrorism and force protection measures have received increased attention within the Department of Defense.

2.7.3.4 Medical Facility Requirements

Unified Facility Criteria 4-510-01 (2012, Nov. 1) provides design guidance for military medical facilities. It addresses the processes for planning, design, and construction. It also identifies hospital unique requirements for building utility systems, architectural elements, force protection, physical security, and equipment. The criteria include hazards assessment and mitigation guidance with an emphasis on seismic, fire, and hazardous material threats.

2.7.3.4.1 Continuity of Operations

The continuity of hospital operations is specifically addressed in two parts of UFC 4-510-01. The regulation describes provisions for designating a hospital "mission essential" and determining if it is required for post-earthquake recovery. The criteria also address planning for contingency operations and military mobilization.

The criteria include provisions for designating a medical treatment facility "mission essential" (Ibid., para. 2-3.4.6). The installation in which it is located must deem it so. Then, the essential functions are identified and the extent of their continuity, under a range of circumstances, is described. These requirements are then included in the project scope and cost. Elsewhere in the criteria (Ibid., para. 11-1.2), there is mention that hospitals tend to be classified as "mission essential" or "mission support." However, the manner in which that determination is made is not described or referenced in the regulation.

In addition to the continuity of operations, UFC 4-510-01 also addresses the ability of military medical facilities to increase their capabilities to meet increased demand during contingency and mobilization operations. Paragraph 2-3.8.7 specifies that a contingency mode concept of operations be developed during the planning phase of projects in which the facility will support contingency operations or military mobilization. In either case, increased health care demands and their impact on the facility support systems are included in the design requirements. Limited aspects of contingency requirements are identified in the criteria, such as the number and type of medical gas outlets at contingency bed locations. Generally, however, the method for determining contingency status and requirements is not described or referenced in the regulation.

2.7.3.4.2 Continuity of Nonstructural Systems

Among the standards in UFC 4-510-01 are a number of measures to establish minimum levels of robustness and redundancy in nonstructural systems. Hospitals are required to have two or more engine generators with at least four days of fuel storage to provide emergency power for life safety, critical care, and equipment loads. Chapter 11 specifies the minimum loads that must be accommodated and provides guidance on the order in which loads are shed in the event one or more emergency generators fail. Water service must be provided by two separate sources, mains, or connections to a multi-source network. The HVAC equipment serving critical care areas shall be on emergency power. Outside plant fiber optic cable and twisted pair copper cable must both be provided with two physically separated, redundant pathways. Areas containing sensitive equipment, like telecommunications rooms, may require independent air conditioning equipment connected to the emergency power system. Similarly, food service refrigerators and freezers should have emergency power and redundant pumps, if using chilled water backup.

2.7.3.4.3 Comparison to Emergency Operations Center Requirements

While functionally very different from hospitals, emergency operations centers (EOC) are another type of building communities expect to be operational during disasters. As such, the planning and design guidance for these essential facilities focuses on the continuity of their operations during significant events. This is primarily accomplished within the existing codes by increasing the risk (occupancy) category of the facility. Unified Facilities Criteria 4-141-04 (2008, Sep. 1, para. 3.2.2.2) states,

> Protection from certain natural threats such as flood, earthquake, snow, wind and fire are addressed by the building code criteria adopted in the UFC 1-200-01. When applying these criteria, an EOC would typically be designated as an “essential” facility, which corresponds to a “Category” IV, or a “Seismic Use Group” III. For the special case where the operations of an EOC has no potential redundancy or cannot be relocated to an alternate location, and must remain operational for the extreme earthquake, wind, or snow event, the facility should be considered as a “national strategic asset’ corresponding to a “Category” V, or a “Seismic Use Group IV, as defined by UFC 3-310-01, Structural Load Data.

Because there is a financial impact to increasing facility robustness and redundancy, the EOC planning and design guidance recommends relying on alternate facilities rather than designing for the most severe disaster events.

> The level of risk determined for the facility should take a balanced approach. Achieving protection levels to eliminate all risk is not required. EOC operations may be relocated to alternate EOC facility locations, and do not need to be designed to withstand the severest threats (Ibid., para. 3-2.2.3).

This approach does not address events that affect large geographic areas or the difficulties associated with relocating in the middle of a severe event.

Neither UFC 3-301-01 (2013, Jun. 1) nor UFC 4-510-01 discuss increasing the risk category of hospitals to Risk Category V "National Strategic Military Asset" to increase facility survivability. They also do not address the difficulty of evacuating patients, staff, and equipment to another hospital during a major disaster.

2.8 Conclusion

Hazards will continue to threaten our communities, infrastructure, and medical treatment facilities. History demonstrates our vulnerability to disasters and the major disruptions these events can wreak. To protect their patients and support their communities, hospitals should take steps to increase their survivability from disruptive events with an eye toward the continuity of health care operations.

Codes and regulations essentially establish aspects of the level of risk hospitals will accept by mandating minimum standards for siting, design and construction, materials, and operational practices. While hazard vulnerability analyses are conducted during the planning phase of a facility replacement or major renovation and by hospital owners to meet regulatory requirements, these activities do not necessarily follow the same approach, rely on the same data and assumptions, or draw on input from the same or similar stakeholders. Greater continuity and standardization in the identification and understanding of our systems, their dependencies and interdependencies, the hazards that threaten our hospitals, the vulnerability of our systems to those hazards, and identification and documentation of mitigation and preparedness actions will go a long way toward improving the quality of our capital investments and strengthening our medical infrastructure.

Chapter 3

METHODOLOGY: DATA COLLECTION AND ANALYSIS

Understanding contemporary, complex problems is challenging because of their trans-disciplinary nature. To solve these problems requires pulling together expert knowledge to support the needs of decision makers. Fostering resilience in health facilities is one such complex problem. We need a more comprehensive understanding of hospital functionality and the risks these organizations face in order to devise more effective ways of ensuring the continuity of health care operations.

Toward that end, this project developed a package of tools to improve the manner in which planners, designers, health care professionals, and emergency managers consider hospitals and their survivability during and after disaster events. The tools are an influence diagram, hazard vulnerability mitigation framework (HVMF), and illustrative optimization model. Their purpose is to improve the planning and design of health care infrastructure.

Initially, I developed preliminary versions of the influence diagram and HVMF based on the literature and my own experience. I presented the early models to expert panels, consisting of health care professionals, who made recommendations for their improvement and helped refine them. In addition, I conducted secondary qualitative and quantitative analysis of data collected from focus groups of medical treatment facility staff members experienced in hospital emergency management who explained the nature hospital operations, described emergency medical support to their communities, and prioritized services immediately following a disaster event.

Collectively the respondents provided insights into hospital functionality, hospital support to communities, and the priority of services and support systems during disasters. They also provided key recommendations for improving and refining the influence diagram and HVMF.

The optimization model was developed for a risk analysis course I took at the University of Delaware (Archibald, Sanchez Gil & Goetschius, 2012). The model allowed us to consider how an extended loss of water would affect an urban hospital following an earthquake event. As included in this project, the model serves as an illustration of the quantification of a loss of service and its impact on the delivery of health care.

This chapter explains the methodology employed for this research. It explains the purpose and origins of the influence diagram and HVMF, the qualitative analysis, and the quantitative analysis. The findings are presented in Chapter 4.

3.1 Influence Diagram

The influence diagram is one of three tools developed as part of this project. This section introduces the model by explaining its purpose and origin.

3.1.1 Purpose

Influence diagrams can serve many purposes. In their most basic form, they show the relationships that exist between various elements in a system. The models can also be structured to depict uncertainties and decision contexts. The uncertainties can be assigned probabilistic values so that influence diagrams form the basis for decision trees or probability trees.

Influence diagrams are a graphic representation of a decision context that supports the visualization of a complex problem to support decision analysis. They are considered expert models where the combined knowledge of many experts creates a diagram depicting the interactions of multiple decision elements. Fundamentally, an influence diagram is a directed graph consisting of nodes and arcs. The nodes represent decisions, uncertainties, and consequences while the arcs represent the influence of one node on another (Clemen, 1996; Morgan, Fischhoff, Bostrom & Atman, 2002).

The expert panel and many participants at the American Meteorological Society's 2013 Building Resilience to Weather for Healthcare Facilities & Services Workshop expressed a need for a more holistic view of hospital systems and systems on which they depend. The influence diagram that is part of this dissertation is one of three tools developed to help us understand the myriad, complex systems and relationships that contribute to the successful delivery of health care in hospitals. It contributes to a common picture of the internal and external elements that support hospital functionality.

My use of the influence diagram is in its most basic form. I show the elements that affect hospital functionality and how those elements relate to one another. The elements included in this model represent both internal hospital systems and the external systems upon which the hospital systems are dependent. The systems are comprised of multiple components, known as subsystems, units, and parts (Perrow, 1984), which are nested within the larger system elements.

3.1.2 Origin of the Model

Many scholars have developed influence diagrams to depict the complexity of infrastructure and health care facilities to make the system elements and their influences easier to understand. Rinaldi, Peerenboom, and Kelly (2001) diagramed the interdependencies of critical infrastructure. Yavari, Chang, and Elwood (2010) and Youance, Nollet, and McClure (2012) created hierarchical diagrams of hospital systems for the study of post-earthquake functionality in health care facilities. McDaniels, Chang, Cole, Mikawoz, and Longstaff (2008) created a conceptual framework (modified flowchart rather than a traditional influence diagram) for understanding the factors that influence pre-disaster resilience in hospital infrastructure. They apply this framework to hospitals to improve the understanding of how decisions can be made to increase robustness and rapidity. Robustness is the ability of a system to maintain function. Rapidity is the speed with which a system can return to full operations.

The framework is comprised of external and internal factors that bear on hospital functionality before a disaster. The factors and influences are clustered into five contexts: socio-technical, pre-disaster planning, vulnerabilities, hazard, and robustness. While the factors are not comprehensive, they represent the type of elements in the five contexts that affect the ability of a hospital to remain operational. Ultimately, all of the factors narrow down to two elements that the authors call technical robustness and organizational robustness, which influence hospital service.

McDaniels et al. (2008) identify five primary uses for their diagram. First, it provides a shared understanding of the systems involved in infrastructure resilience. Second, it shows the interconnectedness of decisions and uncertainties, which allows system managers to visualize their vulnerabilities. This enhances their ability to identify and characterize mitigation and adaptation strategies, which is the third use of the diagram. Fourth, the diagram can be modified to include probabilistic dependence for the uncertainties. Finally, the diagram can be employed as a supporting tool in the prioritization of mitigation alternatives.

The decision diagram provides a broad overview of the decisions and uncertainties that influence hospital functionality, but the lack of specificity can mask some vulnerabilities, dependencies, interdependencies, and opportunities for mitigation and adaptation. Many of the variables are proxies for more complicated concepts. For example, the framework includes age of facility in the vulnerability context. It is there as an indicator of the quality and durability of construction. The underlying assumption is that the facility was designed and built to the codes that were in place at the time of its construction, which may or may not be true. Additionally, age of facility is too simple a proxy to account for full, partial, or utility system renovations. It also does not address hospitals that occupy several connected buildings of varying age.

I used the framework proposed by McDaniels and his colleagues as the initial basis for the development and refinement of my influence diagram. My intention was to expand upon the earlier work and improve the inclusion of nonstructural systems in the model. I believe the resulting model gives hospital decision makers a more complete understanding of the elements and influences that affect their operability during both normal and crisis operations.

3.2 Hazard Vulnerability Mitigation Framework

The HVMF is the second of three tools developed by this project. This section explains its purpose and the origin of the model.

3.2.1 Purpose

Being able to prioritize the application of limited resources is an important aspect of organizational leadership. However, identifying priorities should not blind people to the larger picture. This is particularly true in risk management. When leaders decide to expend money and time on mitigation, preparedness, and planning, they know what they are trying to protect their organization against. At the same time, they should be very aware of what they are less prepared for or are not protected against.

The HVMF is a mental model designed to support a more complete understanding of hazards, disaster agent characteristics, exposure, vulnerabilities, consequences, and protective actions. In its current form, it is not a tool for conducting a hazard vulnerability analysis, nor is it a decision support tool for determining whether to evacuate or shelter in place.

3.2.2 Origin of the Model

The HVMF was created in response to the current state of practice for identifying and analyzing the risks hospitals face. Popular risk analysis practices employed by hospitals in the United States are described in this section along with challenges associated with this approach.

3.2.2.1 Hazard Vulnerability Analysis State of Practice

The Joint Commission first required that accredited hospitals conduct annual hazard vulnerability analysis (HVA) in 2001. Since then, there has not been much scholarly literature on the development or effectiveness of HVA's. Campbell, Trockman, and Walker (2011) identified only three examples of HVA tools created to assist hospitals in the conduct of their analyses. The Kaiser Permanente HVA Tool has been widely adopted and modified by U.S. hospitals and long term care facilities (Occupational Health & Safety Administration, 2006; California Hospital Association, 2011; Vermont Department of Disabilities, Aging and Independent Living, 2010; U.S. Army Public Health Command, 2010; Greater New York Hospital Association, 2004).

In 2005 and 2007, Campbell and his colleagues conducted interviews at eight hospitals in southern Maine to evaluate the quality of their HVA processes. Each of the hospitals used a modified Kaiser Permanente HVA Tool. The researchers found variability in the scope of risk considered and the planning time frames. The commitment of hospital senior leaders to the process affected the resources applied to the analyses and the implementation of the results. Differences were found in the communication of the results and their effect on preparedness activities. Besides the influence of senior leaders, individual participants and the framing of the process affected the outcomes. The researchers also found a general lack of documentation with regard to the decision making process and the divergence of opinions regarding risk. To deal with the variability, Campbell et al. recommend increased standardization of the HVA process, identification of the disciplines that should participate in the assessment, and a reconsideration of the frequency with which HVA's are conducted.

While most models of vulnerability focus on the community level (Wisner, Blaikie, Cannon & Davis, 2004; Cutter et al., 2008; Turner et al., 2003), the Kaiser Permanente Hazard Vulnerability Analysis (HVA) Tool is applied at the organizational level (California Hospital Association, 2011). It is used to identify all the hazards a medical facility may face, which are divided into the categories: natural, technological, human-induced, and hazardous materials. These categories include both internal and external threats. The hazards are characterized in terms of probability and severity (magnitude – mitigation) to determine the residual risk associated with each hazard. At the end, the hazards are rolled up into a summary to compare the risk associated with each category and the probability and severity of any disaster.

As explained by the expert panelists and a representative from The Joint Commission, who presented at the American Meteorological Society's 2013 Building Resilience to Weather for Healthcare Facilities & Services Workshop (Maurer, 2013), once the analysis is complete hospitals focus on the two or three highest risk events, or the events with the greatest severity, and prioritize their emergency preparedness activities based on those threats.

3.2.2.2 Challenges in Analyzing Hazards and Vulnerabilities

Popular HVA tools rely on the preparers to make judgments about the probability and potential impacts of each emergency. This is challenging because individuals tend to over or underestimate risks (Slovic, 2000) and are subject to availability bias, unavailability bias (Tversky & Kahneman, 1973), and probability neglect (Sunstein, 2002). Availability bias describes a person's tendency to overemphasize the probabilities of recent events or significant events that are salient, whereas unavailability bias pertains to a person's inclination to underestimate the probability of an event because similar events cannot be recalled (Kahneman, 2011). Probability neglect is the tendency of people to ignore small probabilities when making decisions under uncertainty. In many cases, very small probabilities are viewed as a zero percent chance of occurrence. Each of these cognitive biases creates challenges for establishing reliable estimates of probability when conducting a hazard vulnerability analysis. As an example of availability bias, a senior staff member in a Tennessee hospital suggested the likelihood of a "crazy man with a semi-automatic" attacking hospital employees was more likely than an internal fire. I believe this statement was influenced by high profile instances of workplace violence involving firearms in the late 1980s and 1990s, some of which led to the cultural term “going postal.”

Due to limited resources, leaders must determine what will receive attention at any given point. Relying on probabilities to establish those priorities is widely considered to be rational. However, trying to parse out the most likely of low probability events with limited data is difficult. Taleb, Goldstein, and Spitznagel (2009) suggest that low probability, high consequence events are almost impossible to forecast and the increasing complexity of modern technology and interdependent systems is even making the forecast of ordinary disruptions more difficult. Rather than focusing our attention on a handful of worst case scenarios, they suggest we would be better served by focusing on consequences or the impacts of disruptive events.

Many of the hazard and vulnerability models acknowledge the role exposure and vulnerability play together to influence the resulting impact of a hazard (Turner et al., 2003). The Kaiser Permanente HVA characterizes exposure and vulnerability in terms of preparedness and response capabilities. However, the tool lacks specificity in the areas of severity, preparedness, and response, which may mask some vulnerability or provide an incomplete picture of the risks faced by the hospitals completing the analysis. While the comparison of categories of hazards or probability and severity are interesting, they do little for staff members who are trying to mitigate and prepare for disruptions to their hospitals. For facility-level planning, specificity is important. Understanding that the threats to the individual components of a system may have disproportionate impacts on that system and other systems is necessary. Detailed knowledge of the system components and their dependencies and interdependencies with other components and systems is critical to gaining a more complete understanding of the hospital's exposure and vulnerabilities. We need a better way of thinking about threats, our vulnerabilities, how we can be affected by disruptions, and, ultimately, how to protect ourselves and our operations. The HVMF is a step in that direction.

3.3 Qualitative Analysis

Throughout the dissertation, I use different terms to describe group interviews for two separate data collection efforts. First, I conducted expert panel interviews and analyzed the transcripts to refine two models I developed. The other was secondary analysis of focus group transcripts from a project studying the incentives and impediments to hospital hazard mitigation in the United States. The expert panel respondents were recognized as experts within at least one of five health care specialties identified for the project. Each person had many years of experience in different hospitals and health care organizations. The comments they provided during the interviews were based on that broad knowledge and were focused on the refinement of two theoretical models rather than simply their personal experiences. The respondents were serving as experts rather than witnesses. The focus group respondents, on the other hand, were answering questions from the perspective of their experience at the hospital that employed them. In that regard, they were responding as witnesses to their experiences at those hospitals and within their communities (Weiss, 1994). This section of the chapter addresses recruitment, respondents, and data collection for the two efforts separately before discussing the data analysis and limitations jointly.

3.3.1 Expert Panels

The purpose of the expert panels was to evaluate the completeness and usefulness of an influence diagram depicting the elements that bear on hospital functionality and the Hazard Vulnerability Mitigation Framework (HVMF) that represents a manner of understanding hazards, exposures, vulnerabilities, consequences, mitigation, and preparedness in a hospital context. Through their comments and discussion, I sought to refine the models and identify steps necessary to operationalize them. The Institutional Review Board (IRB) approval letters for this research can be found in Appendix F.

3.3.1.1 Recruitment and Respondents

Recruitment of the expert panelists began in May 2013. One of my dissertation committee members helped me identify individuals with work experience in military hospitals. The professional specialties sought were health care administration, clinical practice, hospital operations and emergency management, hospital logistics, and facilities management. Once we identified a potential respondent, I emailed a recruitment letter (Appendix G) and handouts describing the influence diagram (Appendix H) and the HVMF (Appendix I) to them. I sent recruitment packages to seven potential respondents and received agreement to participate from six individuals.

I used the website, Doodle Calendar, to coordinate the panelist's schedules and arrange the dates and times for the expert panels. My plan was to hold two 2-hour group interviews, one for the influence diagram and one for the HVMF. I was interested in group interaction and dialogue among the participants to gain a more complete understanding of their points of view, where they agreed, and where they disagreed. After determining everyone's availability, I was able to schedule two group interviews with five respondents and two one-on-one interviews with a respondent who was not available for the group discussions.

3.3.1.2 Data Collection

The expert panels were held in September 2013 near Washington, DC. The five participants represented the five specialties sought. In addition, several of the respondents had served in senior executive positions at military hospitals. Four of the panelists were present in the room while one joined the interview by speaker phone. Both group interviews were audio recorded and transcribed.

The one-on-one interviews were conducted in September and October 2013. The second interview had to be rescheduled once as a result of the Federal Government's shutdown in early October. The interviews were held telephonically, audio recorded, and transcribed.

For both the group and one-on-one interviews, I started with the influence diagram. After having the respondents read and sign the informed consent form (Appendix J), I reviewed their rights with them and answered questions. I relied on an interview guide (Appendix K) to standardize the semi-structured interviews. This approach ensured I asked the respondents the same questions in each of the interviews, but allowed me the flexibility to probe panelist comments and clarify key points

(Bryman, 2012; Patton, 2002). I relied on a separate interview guide (Appendix L), but the same approach, for the HVMF interviews.

The aim of the interviews was to refine the influence diagram and HVMF presented to the panelists. Beyond improving their usefulness as mental models, the respondents also addressed steps toward operationalizing the tools so they would be more useful to planners, architects, engineers, hospital staff members, and emergency managers.

3.3.2 Hospital Rehabilitation, Impediments, and Incentives Project

In 2000, the Multi-Disciplinary Center for Earthquake Engineering Research (MCEER) at the State University of New York at Buffalo and the Disaster Research Center (DRC) at the University of Delaware partnered to conduct a study of impediments and incentives to hospital rehabilitation. The project had three primary objectives (Connell, 2003):

> (1) Identify the impediments and incentives for adoption and implementation of loss-reduction measures with an emphasis on the rehabilitation of existing hospitals; (2) determine what internal and external variables influence these impediments and incentives; and (3) determine the units and systems that are critical to maintain the functionality of a hospital in the time period following a disaster event.

Dr. Joanne Nigg (Primary Investigator) graciously allowed me to use the project data as a part of my dissertation (Appendix M).

3.3.2.1 Recruitment and Respondents

The researchers contacted 29 U.S. acute care hospitals in areas of different seismic risk, of which 13 agreed to participate in the study. The hospitals were located in California, New York, and Tennessee. Within the states, the hospitals represented different sizes (based on bed capacity) and ownership. The respondents represented a range of specialties within the hospital, but consisted of people with responsibilities related to disaster planning and preparedness. In all, 76 respondents from the 13 hospitals participated in the project. A descriptive summary of their characteristics is identified in Table 3.1.

Table 3.1: Descriptive Summary of Hospitals

State	California	New York	Tennessee
Number of Hospitals	4	4	5
Size of Hospitals: Small (<151 beds) Medium (151-300 beds) Large (>300 beds)	1 Small 2 Medium 1 Large	1 Small 2 Medium 1 Large	1 Medium 3 Large 1 Health System
Ownership of Hospitals	3 Not-for-Profit 1 For Profit	3 Not-for-Profit 1 Government	2 Not-for-Profit 1 Government 2 For Profit
Number of Respondents	23	27	26

Among the 13 hospitals, the range of the number of respondents for each interview was three to eight. The mean number of participants was 5.85 and the median was six. They represented the four categories of service within the hospitals: clinical, ancillary, support, and administrative. Among all the respondents, 24 were clinical, three were ancillary, 20 were support, and 29 were administrative.

3.3.2.2 Data Collection

The researchers conducted semi-structured focus groups at each of the hospitals using an interview guide (Appendix N) to ensure consistency among the interviews. The discussions were audio recorded and transcribed. The researchers also asked the respondents to complete surveys ranking the importance of various services and systems, which will be discussed in the quantitative section of this chapter.

3.3.3 Data Analysis of Expert Panels and Focus Groups

Before holding the expert panels, I started the qualitative analysis of the hospital mitigation project focus group transcripts using ATLAS.ti 6.2, a qualitative data analysis software package developed for this purpose. I used the software to document codes, quotes, and memos. I also linked relevant quotes to one another demonstrating relationships for explaining, expanding, or disagreeing among informant comments. My intent was to comprehensively code all words, lines, or paragraphs to capture the ideas and concepts contained therein using an open, inclusive coding approach to be followed by axial coding where individual codes are categorized to represent broader, abstract concepts (Strauss & Corbin, 1998; Saldaña, 2013).

After analyzing four transcripts, I reviewed the process to determine if I was getting what I needed for my research. I had generated 114 codes, 12 code families (categories), and 67 memos from 471 quotes. While the process was rigorous, I found that I was capturing data that was interesting but not relevant to my research. Because the hospital mitigation project was being conducted in the wake of California's passage of Senate Bill 1953, which mandated broad assessments of the seismic risk to hospitals, many health care organizations were fearful that they would be forced out of business if they could not afford to retrofit their buildings. The respondents' explanations of the interactions between the hospitals and the Office of Statewide Health Planning of Development as the state determined how the law would be interpreted and implemented were interesting, but they did not inform community support and hospital functionality in a manner that was pertinent to my research.

Strauss and Corbin (1998) note the procedures and techniques for conducting open coding are not rigid. They can be omitted or modified to meet the needs of the research and the researcher. After discussing the analysis with my committee chair, we agreed I would try an analytic process that focused on data relevant to my project. I would continue the two-step coding process of labeling key points and concepts followed by classifying them into categories. However, I would not code every phrase or idea in the transcripts but, instead, focus on those concepts that were relevant (Saldaña, 2013) to the two models and hospital functionality, more broadly.

For the remaining nine focus group transcripts from the hospital project, I continued my initial coding by handwriting codes and short notes in the margins of a hard copy of each transcript and underlining key quotes and phrases. During this phase of the analysis, I primarily applied descriptive and in vivo codes to the interviews. These are codes that either describe a particular concept or are drawn specifically from the language used by the respondents. For example, "community disaster planning" is a descriptive code I used to denote the wide range of hospital activities that support community disaster planning, including participation in disaster drills, attending planning meetings, complying with regulatory requirements and associated with community support during disasters. Examples of in vivo codes that were developed during the initial coding process are "loss of hospital wing" and "institutional memory."

I also wrote longer memos and gathered them together in a text document. The memos contained particularly relevant quotes and my own summary of key ideas or points made by respondents. Some memos contained the synthesis of ideas and findings from multiple sources when I found the convergence or divergence of concepts between them. After completing the initial coding of the transcripts, I created a mind map containing the coded quotes and memos using Mindjet's MindManager 2012 Professional. The mind map allowed me to dynamically organize and reorganize the ideas and concepts, which was critical to forming meaningful categories. Ultimately, the categories informed the refinement of my understanding of community support and hospital functionality, which is presented in Chapter 4.

I continued the manual approach to qualitative analysis with the data gathered from the expert panels. I took limited handwritten notes during the interviews. However, I wrote notes documenting key points and summarizing my thoughts within 24-hours of each discussion. Once all of the focus groups and one-on-one interviews were complete, the audio recordings were transcribed. Again, I labeled relevant ideas and concepts, wrote memos summarizing key points and synthesizing ideas, and entered the coded data and memos into the mind map that I started with the hospital hazard mitigation project data. As I was working through the qualitative analysis, I found myself moving up and down in terms of specificity. I identified descriptive and in vivo codes, categories (e.g., individual building utility systems were categorized as "nonstructural systems"), and rough theories simultaneously while analyzing the transcripts from my expert panels and the focus groups from the hospital mitigation project.

With the initial coding of the two projects combined, I was able to develop and refine meaningful categories that allowed me to see how the data informed hospital support to communities during disasters, hospital functionality, the influence diagram, and the HVMF. I grouped the quotes and memos into those four broad areas and categorized them based on common attributes. This process revealed meaning in the data and enhanced my understanding of how hospitals support communities during disruptive events and remain operational. It also enabled the evolution of the two models so they are more comprehensive and may be operationalized. The results are reported in Sections 4.4 and 4.5.

3.3.4 Limitations of the Research

There are a number of limitations associated with this research. They are inherent in qualitative approaches, secondary data analysis, and sample selection (Bryman, 2012). To the extent possible, I mitigated their negative effects or acknowledged their existence and maintained that awareness when conducting the analysis.

I used an inductive coding technique to analyze the qualitative data collected from the expert panels and the hazard mitigation project focus groups. I allowed the data to reveal the relevant codes, but it is likely that my experience as a health facilities planner, my review of the literature pertaining to hospitals and emergency management, and the act of developing the research project influenced how I understood what I was hearing and reading. This may have resulted in something approaching quasi-deductive analysis. To counteract any biases I had, I maintained an open mind, took extensive memos documenting my thoughts, and paid particular attention when I had a positive or negative reaction to the data.

I conducted secondary analysis on the focus group transcripts from the Hospital Rehabilitation, Impediments, and Incentives Project. Had I conducted those interviews for this research, I may have worded some questions differently and asked some additional questions. I would have delved into hospital functionality in a way that did not emphasize quantifiable resources such as beds, patient census, and staffing levels. I would, also, have sought clarification on the similarities and differences between community and hospital expectations of hospital capabilities during and after major disruptions.

The number of respondents participating in the interviews was fairly small. Only six experts contributed to the discussions about the influence diagram and the HVMF. The hospital hazard mitigation project had 76 respondents from 13 hospitals in three states. While these informants were all experts in health care delivery and hospital operations, it is reasonable to assume they do not represent the full breadth of knowledge and opinion on the topics of health care emergency management or hospital planning and design. However, their insights are valuable and, collectively, they provide an informed view of these topics that contributes to a greater understanding of hospitals and their dependent systems, hospital functionality and community support, and the links between hazards, hospital vulnerabilities, and protective action.

The six expert panelists interviewed to refine the influence diagram and HVMF all work, or worked, in military hospitals and the Military Health System. That environment shaped their experiences and their points of view. However, the delivery of health care is fundamentally the same within hospitals all over the United States. They must all meet the same standards to be accredited by The Joint Commission, their health care providers meet state and national licensure requirements, and they deliver a community service in a resource constrained environment. While there are differences between military and civilian hospitals, I believe there are more similarities.

3.4 Quantitative Analysis

Quantitative analysis of survey data obtained from the respondents of the Hospital Rehabilitation, Impediments, and Incentives Project used descriptive statistics. The following section describes the data collection, data analysis, and limitations of that analysis.

3.4.1 Data Collection

In addition to the group interviews, the hospital hazard mitigation project researchers asked the respondents to rate the importance of hospital services, nonstructural systems, and external lifelines within the first 72-hours of a disaster. The ratings were on a seven point scale from “essential” (1) to “not essential” (7) for hospital services and “very important” (1) to “not very important” (7) for nonstructural systems and lifelines, as shown in Table 3.2.

Table 3.2: Ratings of Essentialness and Importance

Hospital Services	Nonstructural Systems	External Lifelines
1 – Essential ••• 7 – Not Essential	1 – Very Important ••• 7 – Not Very Important	1 – Very Important ••• 7 – Not Very Important

The respondents also identified the three most important services or systems during the same 72-hour period. The rating forms are included in the appendices. The hospital service form is Appendix O, the nonstructural system form is Appendix P, and the lifeline form is Appendix Q.

3.4.2 Data Analysis

To analyze the data collected from the rating forms, I entered it into a spreadsheet in Microsoft Excel 2007. Because of the small sample size, the analysis I performed was limited to descriptive statistics. I generated mean, median, and mode values for the services and systems, which are shown in Table 3.3. I also created histograms to evaluate the frequency of specific ratings for each service or system. Where the frequencies indicated a clear preference among the respondents, the summary chart was adequate to reflect the findings. However, if a histogram indicated a divergence of opinions on the importance of a particular service or system, I further analyzed the data by hospital location, hospital size, hospital ownership, and the service of the respondent to parse out the source of the variability. The charts depicting the ratings are located in the appendices. The histograms and findings for hospital service are Appendix R, for nonstructural systems are Appendix S, and for lifelines are Appendix T.

Table 3.3: Importance Rankings of Hospital Services and Support Systems

Hospital Services	Mean	Median	Mode
Trauma/Emergency	1.12	1.00	1.00
Blood Bank	1.29	1.00	1.00
Operating Rooms	1.36	1.00	1.00
Intensive Care/Critical Care Unit	1.49	1.00	1.00
Laboratory	1.57	1.00	1.00
Radiology	1.58	1.00	1.00
Nursing Care Units	1.64	1.00	1.00
Pharmacy	1.70	1.00	1.00
Recovery	2.04	2.00	1.00
Central Supply	2.10	2.00	1.00
Imaging	2.34	2.00	1.00
Dietary	2.58	2.50	1.00
Neonatal Intensive Care Unit	2.80	2.00	1.00

Table 3.3 continued

Housekeeping	3.08	3.00	4.00
Medical Records	3.34	3.00	3.00
Obstetrics/Gynecology	3.56	4.00	4.00
Laundry	3.62	3.00	3.00
Nonstructural Systems	**Mean**	**Median**	**Mode**
Electrical	1.31	1.00	1.00
Med Gases	1.39	1.00	1.00
Lighting	1.67	1.00	1.00
Communications	1.71	1.00	1.00
Ventilation	1.79	2.00	1.00
Plumbing	1.95	2.00	1.00
Steam Sterilization	2.17	2.00	1.00
Fire Alarm	2.21	2.00	1.00
Refrigeration	2.25	2.00	1.00
Fire Sprinklers	2.26	2.00	1.00
Heating	3.05	3.00	3.00
Air Conditioning	3.34	3.00	3.00
Computers	3.43	3.00	3.00
External Lifelines	**Mean**	**Median**	**Mode**
Water	1.40	1.00	1.00
Electrical	1.64	1.00	1.00
Telephone	2.08	2.00	1.00
Transportation	2.14	2.00	1.00
Sewage	2.16	2.00	2.00
Natural Gas	2.78	2.50	1.00
Data Communications	3.28	3.00	2.00

3.4.3 Limitations of the Analysis

There are some limitations associated with this analysis. It is all dependent on secondary data analysis, the rated items were not defined in the survey, all the ratings were based on the first 72-hours of a disaster, and the sample size is small.

I conducted secondary analysis on the quantitative data gathered for the hospital hazard mitigation project. Had I created the surveys myself, I would have identified the hospital services, nonstructural systems, and lifelines somewhat differently. I likely would have included computed tomography and magnetic resonance imaging capabilities among radiology rather than separating them as imaging. I also may have combined heating, ventilation, and air conditioning as a single item instead of three separate items. Given that not all hospitals refer to their services in the same way or rely upon the same utility systems, the addition of definitions describing what was included in each of the headings may have been useful. This is particularly true given the complexity of many of these and the connections they have with other systems or services.

The ratings of essentialness and importance were predicated on the first 72-hours of a disaster. The timeframe is based on disaster preparedness standards of practice, but there is nothing unique about three days that makes it a more useful benchmark than 96 hours, five days, or another measure. While conventional wisdom suggests external support may take three days to arrive and get organized, Hurricane Katrina proved that is not always the case as several hospitals were not evacuated until four and five days after landfall (Fink, 2013; Gray & Hebert, 2006). It is possible respondents may have rated some services and systems differently had another timeframe been used, or no timeframe at all.

With only 76 respondents from 13 hospitals in three states, the sample size for the surveys is small. However, the informants do represent hospitals of varying location, size, ownership, and seismic risk. The findings are not generalizable to the U.S., but they do offer insights. Some of the findings are in line with other research, while others are not. The findings and comparisons with other studies are presented in Appendix R, Appendix S, and Appendix T.

Chapter 4

FINDINGS AND TOOLS

4.1 Introduction

This chapter describes the findings and tools developed during this research project to inform a policy recommendation to the U.S. Army that will improve the manner in which the Service approaches the planning and design of military medical facilities. The tools and findings do this in four primary ways. First, the tools broaden stakeholder understanding of the various elements necessary to maintain a functioning hospital during a disaster and their relationships to one another. Second, they provide the medical community with a systematic method of evaluating hazards and vulnerabilities in the context of continuous medical care. Third, they offer a method of considering mitigation and preparedness options relying on scenario based optimization. Fourth, they provide insights from the analysis of input from expert panels of health care professionals and hospital staff focus groups into the factors that affect hospital functionality and community support. Collectively these tools support the development of a policy recommendation to more systematically consider risks to hospital functionality posed by disruptions to nonstructural systems intended to improve the Army's approach to increasing the survivability of medical treatment facilities during disasters. The tools and knowledge should be applied during project development and carried through execution and hand over. Ultimately, the policy recommendation links project planning and development to hospital emergency management planning. Decisions about capital investments should account for operational priorities during disruptive events. If we expect our facilities to remain functional during disasters, this should be known and considered during the planning, programming, and design phases of a project. We may need to take mitigation measures that go beyond basic code requirements to increase the likelihood of post-disaster operability. In many cases, code requirements are focused on safety (protection from death or injury) rather than continuity of operations.

4.2 Community Support

Hospitals serve an important role during emergencies and disasters to care for the injured and the sick. As receivers of those in need, medical treatment facilities must be prepared for a variety of situations and circumstances. As one of the hospital mitigation project respondents explained, "Our job is to be ready, and when they bring them to us, to do the best that we can." Hospitals and their staffs tend to be problem solvers. They provide a service to those in need. It goes against their culture to turn someone away.

Hospital support to communities can be characterized in a number of ways. Designated responsibilities may be derived from geography, patient acuity, and, in non-emergency situations, beneficiary status. Unique capabilities may differentiate a hospital based on health care or disaster response resources. Hospitals also have formal and informal arrangements to support one another in circumstances where health care demands exceed the resources available. Finally, many people consider hospitals to be a safe haven. They are viewed as a refuge and a source of assistance during a disaster event.

4.2.1 Designated Responsibilities

Hospitals may have designated responsibilities within a community based on geography, patient acuity, a combination of the two, and beneficiary status. Urban and suburban areas may be divided into zones based on proximity to local hospitals so that patients picked up by Emergency Medical Services (EMS) are likely to be transported to a particular hospital. These divisions may also be based on the severity of an injury or illness. Hospitals designated as trauma facilities have unique capabilities that enable them to treat the most severely injured. Many communities may rely on a regional facility to provide that level of care. For larger cities, the area may be divided into zones so that trauma patients within a given area are taken to a particular hospital. For example, the City of San Antonio is divided so that trauma patients from different parts of the city go to specific hospitals. This is designed so that the different hospitals share the trauma load and it speeds the transport of trauma patients to definitive care. Beneficiary status can play a role in determining which facility a patient goes to, also. After Hurricane Katrina, some TRICARE beneficiaries from Louisiana and Mississippi were evacuated to military medical facilities in other states.

These divisions of designated responsibility are most applicable to patients who are transported by an EMS system. People who self-transport or are taken to the hospital by family or friends are not likely to follow the same procedures for determining where they should go. Auf der Heide (2006) found that during disaster events, most people are not transported to hospitals by ambulance. Instead, they go to the nearest medical treatment facility, or the one with which they are most familiar, via personal automobile, mass transit, taxi, other first responder vehicle, or by walking. By going to the nearest or most familiar hospital, it is possible that the facility will be ill-prepared for the medical needs of the patient.

4.2.2 Unique Capabilities

Some hospitals have unique capabilities that enable them to respond to particular injuries, illnesses, or disaster events more effectively than other organizations. Tertiary and quaternary care facilities have specialty and subspecialty services that cannot be found in lower level hospitals. In some areas, there may only be one tertiary hospital close by making it particularly unique.

> We have . . . an ownership responsibility, as we are responsible for our city and county. Greater than that, we are the only tertiary care facility outside of [two major cities in the state], so there's a greater ownership for responsibility that we [have].

Similarly, trauma hospitals earn that title by meeting local or state standards indicating a higher level of severe injury care than is expected at a facility without that designation. Unique capabilities may also extend to disaster related facilities, equipment, and organizational capabilities. For example, some hospitals have special facilities and equipment to respond to radiological contamination that is not available elsewhere in their jurisdiction.

> We do an annual hazardous materials drill with the county in conjunction with the other hospitals. We are also under the state plan in regards to weapons of mass destruction. If something were to happen for instance . . . with the power plants . . . we are named as an alternate source . . . in radiological instances. We'd be used as a health care facility.

This makes them are a strategic asset for the community they serve.

4.2.3 Mutual Aid

The culture of service that pervades U.S. hospitals and the ethical position espoused by the Hippocratic Oath set the tone for organizations that do what they can to support patients in need of their services. Many hospitals establish mutual aid agreements or health care coalitions to formalize relationships between organizations and ensure support during disaster events. These actions are based on a desire to protect their patients. In some cases, these arrangements extend to nursing homes and long term care facilities (Disaster Research Center, 2012). However, hospitals that are proximate to one another will frequently help each other even if there is no formal, written agreement. One of the respondents to the hospital mitigation project explained how external vendors and nearby health care facilities came to each other's aid during emergencies and disasters.

> . . . we . . . have an internal coffee shop, which is an outside vendor, who is extremely cooperative. When there's a problem, he will supply coffee and juices and water and food, if necessary. So we just make sure that everybody has what they need to get by. And in house, our stock isn't very large, but again, we have the resources. You know, it's not on paper, but next door is [another] medical center. We need something, they'll help us, and vice versa. Next door to [one of our hospitals], you have [another] medical center. We need something, they'll help us. And we also have a partnership, letters of agreement, with six or seven nursing homes in the community. That if we need to discharge people out, we can get them out.

This indicates a sense of community and shared purpose among medical treatment facilities.

4.2.4 Safe Havens

Many people view hospitals as a beacon or safe haven during disasters. These include people seeking medical treatment and those in need of medications for acute and chronic conditions. Hospitals also draw individuals looking for family members or friends and journalists in search of a story.

Some people go to hospitals seeking refuge from difficult and uncertain circumstances elsewhere in the community. Medical treatment facilities can offer safety, heat or air conditioning, food, water, and a dry place. Because hospitals are usually in contact with emergency services and other health facilities, they are also a source of information.

Hospitals serve as a shelter for many people. Some health facilities allow staff members to bring their family members and pets to the facility during a disaster to alleviate role conflict. Also, in some cases, hospitals are designated as community shelters. One of the respondents to the Hospital Rehabilitation, Impediments, and Incentives study explains the various responsibilities their hospital has during a disaster, including treating patients and sheltering the displaced.

> I think firstly would be treatment of patients, treatment of injured let's say. Secondly, we are also a designated shelter for those people who are homeless or displaced during a disaster. So, we do have a [provider education] building that is attached to the hospital and we are first, other than treatment of injured, our second focus I should say is designating areas that we could move people out or combined people to make rooms available to house people who have been displaced.

The role of hospital as designated shelter extends to military medical treatment facilities, too. The Bassett Army Community Hospital at Fort Wainwright in Fairbanks, Alaska was designed and constructed to the essential facility standards in the military medical facility design guide. Additionally, a community shelter was incorporated into the hospital's basement.

4.2.5 Challenges

The role hospitals play supporting communities during disasters is not without its challenges. Different types of ownership, business competition among hospitals, and organizational priorities all affect community support and disaster preparedness decisions. Financial imperatives drive many, if not most, hospital decisions rather than community health needs. While resources are certainly finite, the people making decisions are frequently far removed from the implications of their decisions (Hanfling et al., 2013).

4.3 Hospital Functionality

Hospital functionality is fundamentally about medical treatment facilities meeting the health care demands of their patients. It can be studied and described from different perspectives. However, it comes down to basic problem solving. Hospital staffs identify problems and apply the resources they have to solve them. They do this every day throughout the facility. New patients present at all hours with a wide range of illnesses or injuries seeking care that will cure or mend them. Clinicians must evaluate the situation, diagnose the problem, determine an appropriate treatment, and implement that treatment. For that to be possible, a great many support tools and systems need to be in place. The diagnostic resources such as radiological and laboratory equipment, complex building utility systems that deliver electricity, water, and medical gases, protocols that govern infection control to protect both the patient and the practitioner from greater harm, and inventory management systems that ensure the necessary pharmaceuticals and medical supplies are available when needed all exist so that the individual clinician can deliver health care to the patient.

To understand and characterize this functionality, we need to appreciate what is essential to the delivery of health care. What is necessary for a patient to access services? How do hospitals meet the varied demands of the community? How do hospitals adjust when demands increase rapidly, like during a disaster? This section discusses the characterizations of capability, capacity, flexibility, and the prioritization of services.

4.3.1 Capability and Capacity

Capability is a function of the services a hospital can provide to assess, diagnose, treat, and rehabilitate patients. The physician and nursing specialties, medical equipment, pharmaceuticals, and protocols present within the facility all play a role in the capabilities of the hospital. Not all hospitals are the same. Some are staffed and equipped to handle trauma cases while others are not. Some possess medical specialties and subspecialties and receive patients who are referred by other hospitals.

For a hospital, capacity is generally understood as its ability to provide care for patients such as the number of people who can be cared for at a given time. This view frequently leads to the use of proxy measures for capacity. The interviewers and respondents for the Hospital Rehabilitation, Impediments, and Incentives project frequently spoke about capacity in terms of the number of inpatients beds a hospital had, the number of staff per shift, or the number of patient visits, either as daily census or per annum.

> We are budgeted for 267 beds. . . . We are licensed for 537, but we would never operate at that. . . . Our occupancy is probably 75 percent of that on any given day, but on a 24-hour shift, we probably have a maximum utilization of all of our beds.

> Our everyday volume averages between 130 and 140 patients per day on a normal day, which the break down is the largest percentages on the afternoon shift or to midnight and the lowest number, about 20 of those visits, would be midnight to 8:00 a.m. The remainder is in the morning. Both physician and nursing staffing is basically adjusted to those volumes with the highest number of nurses in the evening and the lowest number, you know, night and early morning.

> We have over, or roughly, 3,000 or 3,300 employees: full time, contract, and temporary. I say again that 60 to 70 percent of them are on the day shift.

The national Hospital Available Beds for Emergencies and Disasters (HAvBED) is an electronic system in which hospitals provide their bed availability status on a daily basis as part of the National Disaster Medical System. That dashboard decision support tool uses occupied, staffed, and unstaffed inpatient beds as proxies for capacity. The underlying assumption is that if you have a "staffed bed," such as an intensive care unit bed, you also have the corresponding staff, equipment, supplies, and utilities necessary to support a patient in that bed.

Beyond merely counting individual beds or staff members, capacity can also be considered over time. How many patients can be treated over a given period of time? This is throughput. One of the expert panelists provided a broad overview of how a patient moves from admission to discharge using an orthopedic example and described how capacity at different points can affect the speed at which the patient moves through the hospital.

> There's appointment systems . . . that rely on telephony to make the appointment. They are integrated with the scheduling systems. There's a capacity issue there. That really is reliant upon demand and the actual networking systems within the hospital to keep up with that demand. Then, once they get in the hospital itself, there's a capacity issue in terms of what they need for their orthopedic complaint. Their ability to . . . get that surgical service. There's all sorts of reliant systems, supply systems that provide implants, the CMS [Central Material Service], and . . . things along those lines. Then, the post care episodes, the physical therapy. . . . Everything else should be done on an outpatient basis.

This view of capacity recognizes the many steps a patient goes through from admission to discharge. It acknowledges that high demand for limited resources creates bottlenecks. A limited number of operating rooms can force patients on the med-surg wards, or in the ICU, to wait for surgery. Because the number of inpatient beds is finite, those delays can trickle down to the emergency room, where many people are assessed and admitted to the hospital. Without available beds, in which to be admitted, patients take up an emergency bed. That leads to extended wait times in the emergency department's waiting room.

4.3.2 Flexibility

The importance of flexibility, innovation, and improvisation in response to change and unexpected circumstances has been argued by many social scientists. The DRC typology of organizational behavior categorizes the manner in which organizations adapt themselves and their actions to meet changing demands in terms of established, expanding, extending, and emergent responses (Dynes, 1970; Kreps & Bosworth, 2006). Kreps (1991) emphasizes the importance of improvisation in maintaining flexibility during changing circumstances and how preparedness and improvisation are closely linked in successful emergency management. Wachtendorf and Kendra (2012) describe improvising solutions to reproduce lost resources and capabilities. Weicke and Sutcliffe (2007) explain how high reliability organizations employ mindfulness (hyper-alertness) to halt or contain unexpected events and quickly restore normal operations through flexible functioning.

The surge literature recognizes the combination of staff, structure, and stuff is what allows hospitals to meet increased demands during disaster events. Staff consists of the hospital employees who provide health care and keep the hospital running. Structure has two parts. It is the physical building with all of its utilities and support systems. Structure is also the organizational framework that establishes the way people work together. It guides normal operational relationships and allows for different relationships during disasters to meet changes in patient demand. Stuff includes all the equipment and supplies hospitals use in the course of their operations.

Beyond the existence of these resources is an organization that can employ them in proven or novel ways to ensure the safety and care of their patients, staff, and visitors. Hospitals are fundamentally problem solving organizations. Clinical staff members continuously apply problem identification, course of action development, alternative selection, and implementation as they assess patients, diagnose illnesses and injuries, and identify and apply treatments. Ancillary, support, and administrative staff members implement similar problem solving techniques to keep the hospital functioning in the delivery of care. Whether identifying alternate sources of supply in response to supply chain disruptions, realigning staff members to deal with an increase in patient demands, or procuring additional laboratory equipment to increase diagnostic capabilities and capacity, hospitals are problem solving organizations.

To be effective, these organizations must be flexible and have the ability to innovate and improvise. That means they are responsive to change, can identify and implement novel solutions, and are able to use available resources to solve problems with little or no preparation. These are characteristics hospitals exhibit regularly as they face daily surges of patients, supply shortages, inoperable pieces of equipment, utility disruptions, and staff member absences. One of the hospital mitigation project respondents described how they improvised during a power outage to the hospital's laboratory, which serves an essential diagnostic function.

> When the power went out, it literally shut down all power to the main laboratory. Because of the Y2K preparedness, we had generators and extension cords and everything on hand so pretty much everybody responded, and we kept the lab running because I don't think we had any down time at all.

Organizational flexibility was also exhibited by the Community Medical Center in Tom's River, New Jersey in the wake of Hurricane Sandy. The hospital coordinated with local pharmacies, gas stations, groceries, and shelters to help make certain the needs of its staff, their families, and local citizens were being met. These activities were outside the hospital's primary mission but important for supporting the delivery of health care. As people from the community arrived at the hospital seeking medications, the organization's leaders realized they needed local pharmacies to continue providing their dispensing services because the hospital was not staffed or supplied to support the community in that manner. Similarly, the hospital coordinated with local gas stations to make sure its staff would continue to be able to get fuel for their privately owned vehicles to get back-and-forth from home to work. The facility staff worked with local groceries to make food available for patients, staff, their families, visitors, and citizens seeking shelter at the hospital. The hospital also coordinated with shelters to find alternate safe havens for local citizens (Bryant, 2013). In terms of the DRC typology, the hospital's dispensing pharmaceuticals to citizens who are not patients would be categorized as expanding behavior. The coordination of fuel, food, and shelter was emergent behavior.

In addition to remaining flexible to meet changing demands, hospitals recognize there will be times when their available resources are overwhelmed and they must change the way they delivery health care. In this way, a key difference between day-to-day and disaster operations is the application of principles of medical ethics. The Institute of Medicine (Hanfling, Hick & Stroud, 2013) report addressing indicators and triggers for crisis standards of care suggests that care exists on a continuum: CONVENTIONAL – CONTINGENCY – CRISIS. Conventional care is normal, routine, and conducted on a daily basis. Contingency care is functionally equivalent, which means substitutions are applied to reach the same or a similar effect.

Crisis care involves a shift from patient-centric to population-centric outcomes with significant adjustments to the methods and locations of health care delivery (Ibid). The continuum of care assumes severe restrictions on resources that force a new approach during extreme events (i.e., crisis care).

4.3.3 Prioritization of Services

In the shift from conventional to contingency or crisis care, the demands on the limited resources of the hospital require priorities to be made. Hospital leaders must decide if they will curtail some services in order to shift staff and other resources to more critical demands. Preparing for such an eventuality should be done as part of the emergency planning process.

To determine what is necessary for a hospital to function during disaster events, the expert panelists agreed health care organizations must identify those essential tasks that will be performed during extreme circumstances. These particular services will be prioritized above other services. This idea is drawn from Department of Defense doctrine and is described in the Joint Mission Essential Task List (METL) Development Handbook (U.S. Department of Defense, 2002). The basic premise is that given limited resources, leaders must prioritize those activities they will focus on to achieve their mission requirements. In military tactical units, the METL is used to prioritize and shape training activities. In a health care environment, a METL could identify the priority of services and those functions that can be curtailed to realign resources elsewhere. One of the expert panelists explained prioritization based on METLs like this.

> What are your METLs? . . . These are the bare minimum things I have to provide. . . . Sorry, you don't get your physical therapy that week, or you don't get to see the psychiatrist, psychologist, or social worker

> that week. But, in terms of patient care, the emergency room or things like that may be critical to run your facility.

Another panelist responded with,

> What are the critical functions that need to take place in that situation? Because you're right, during a disaster, who cares about physical therapy? I will tell you that from a functional standpoint of a hospital, a lot of the building components in these systems need to be operational, not necessarily everybody at 100 percent, but . . . you need an emergency power system to be capable as well as the normal power system. . . . You also have the building control systems . . . the HVAC, the chillers, the air, and everything else working to provide the room conditions to be able to do the surgical procedures. So it's a lot of these building components orchestrated in unison to make that delivery because if the lights aren't on, you're not going to be able to do some of that care anyhow. My point is it's all a minimalist list of those functions and utility systems that have to be in operation in order to provide any of those hospital services at all.

The process of identifying mission essential tasks and prioritizing services and functions requires leaders and planners be very knowledgeable about the manner in which the hospital delivers health care and the systems necessary to support it. Many essential elements, and the relationship they have with other systems, are hidden or are external to the hospital and less familiar to those in the medical treatment facility. A model showing the systems and their interrelationships would be beneficial to understanding the complexity of hospital functionality in a more comprehensive way.

4.4 Influence Diagram

The influence diagram is one of three tools developed as part of this project. This section discusses its structure and how the diagram can be operationalized.

4.4.1 Structure of the Model

While there is no single strategy for developing an influence diagram, Clemen (1996) identifies a three step process for creating a decision model. First, identify and structure the values and objectives, which include both fundamental and means objectives. Second, structure the elements of the decision situation into a logical framework, such as an influence diagram or decision tree. Decision elements include relevant objectives, decisions, uncertainties, and consequences. Finally, refine and define all elements of the decision model.

Following Clemen's approach, we identified and structured the objectives associated with the problem. The fundamental objective is to maintain a functional hospital during and after a disaster event in order to achieve the strategic objective of having the hospital available to support community disaster response. The means objectives are to maximize the availability of the hospital's internal and external systems.

We structured these objectives in a table that identifies the systems and their components, dependencies and influences among and within the systems, the goals for achieving the objectives, and characteristics of effectiveness for achieving the goals. To explain the table more easily, I have broken the means-objectives up by system and included them in this text. The table of objectives can be found in its complete form in Appendix U.

4.4.1.1 Objectives

The systems necessary for a functional hospital can be divided between those that are internal to the facility and those that are external to it. The internal systems are hospital services, personnel, structural, and nonstructural. The external systems are lifelines, the supply chain, transportation, and community services. Together they support the delivery of health care.

4.4.1.1.1 Hospital Services

Hospital services include all activities in the hospital that pertain directly or indirectly to patient care. These services involve treatment, diagnosis, therapy, custodial care, support, and administration. Inherent in these are the organization of staff and the administrative procedures that dictate how the hospital functions. Table 4.1 identifies the means-objectives related to hospital services.

Table 4.1: Means-Objectives for Hospital Services

SYSTEM	Hospital Services	Hospital Services	Hospital Services	Hospital Services
SUBSYSTEM	Treatment Services	Ancillary Services	Support Services	Administrative Services
COMPONENTS	Emergency; Surgery; Medical; Psychiatric	Diagnostic (Laboratory, Radiology, Audiology); Therapeutic (Pharmacy, Physical Therapy, Occupational Therapy); Custodial (Assisted Living, Skilled Nursing)	Dining; Social Work; Religious Services; Medical Equipment Management; Facility Management; Medical Logistics; Medical Transportation; Sterilization; Housekeeping	Admissions; Records; Discharge; Healthcare Administration; Human Resources; Resource Management; Safety; Patient Advocate; Infection Control; Patient Safety; Quality Management
DEPENDENCY	Hospital Staff; Structural Systems; Nonstructural Systems	Hospital Staff; Structural Systems; Nonstructural Systems	Hospital Staff; Structural Systems; Nonstructural Systems	Hospital Staff; Structural Systems; Nonstructural Systems
INFLUENCE	Functional Hospital	Functional Hospital	Functional Hospital	Functional Hospital
MEANS-OBJECTIVES	Maximize availability of treatment services.	Maximize availability of ancillary services.	Maximize availability of support services.	Maximize availability of administrative services.
CHARACTERISTICS OF EFFECTIVENESS	Capacity; Availability; Throughput; Quality	Capacity; Availability; Throughput; Quality	Availability; Capacity; Agility (responsiveness)	Availability; Capacity; Agility (responsiveness)

To provide adequate care, the hospital services are dependent on trained staff members who are organized into effective teams. The services are also dependent on structural and nonstructural systems to maintain the facility and its spaces, deliver the necessary utility services, and provide the essential equipment and supplies. Each of these is required for a hospital to remain functional. Thus, the means to support hospital functionality are to maximize the availability of these services.

To achieve the availability of these services, we must focus on several characteristics: capacity, availability, throughput, quality, and agility.

Capacity: Capacity is the number of patients a particular service can care for at a given time. Capacity can be understood in terms of physical space, beds and equipment, trained staff, pharmaceuticals, and medical supplies.

Availability: Availability is the existence of appropriate and necessary services at a particular time.

Throughput: Throughput is the flow of patients through treatment and ancillary services during the provision of care from admittance to discharge. Therefore, it is a measure of patient volume over time. Throughput is related to capacity in that one service must have excess capacity in order to receive a patient from another service and continue the flow of health care.

Quality: Quality relates to health care meeting acceptable standards of practice in keeping with protocols, regulations and laws.

Agility: This is the ability of support and administrative services to respond to the demands of health care delivery. It is most commonly understood in terms of meeting the demands of surge or increased patient volume and acuity.

4.4.1.1.2 Nonstructural Systems

The nonstructural system consists of three subsystems: architectural elements, building utilities, and building contents. These are necessary for the proper functioning of the hospital services. Table 4.2 identifies the means-objectives related to some of the nonstructural subsystems. A complete table of systems and components can be found in Appendix U. The objectives below are representative of the others.

Table 4.2: Means-Objectives for Nonstructural System

SYSTEM	Nonstructural	Nonstructural	Nonstructural	Nonstructural
SUBSYSTEM	Architectural Elements	Building Utility Systems (Water)	Building Utility Systems (Electrical)	Building Contents
COMPONENTS	Windows; Shutters; Doors; Wall Partitions; Ceilings; Lighting; Exterior Panels and Veneer; Parapets; Curtain Walls	Pumps; Boilers; Storage Tanks; Piping; Fixtures	Service Entrance Equipment (Transformers, Switch/Service Disconnects, Fuses, Circuit Breakers, Meters, Controls, Wires); Interior Distribution Equipment (Conductors, Raceways, Conduit; Subpanels, Submeters, Wires); Loads (Lighting, Motors, Equipment, Etc); Back-up Equipment (Generator, Fuel Storage, Transformer, Transfer Switch, Circuit Breakers, Meters, Controls)	Computer Equipment; Communications Equipment; Food Service Equipment; Laundry Equipment; Medical Equipment; Pharmaceuticals; Medical Supplies; Medical Gas Cylinders; Library Stacks; Shelving; Cabinets; Furniture; Movable Partitions; Lockers; Vending Machines
DEPENDENCY	Structural System; Building Utility Systems	Water Lifeline; Electricity; Medical Logistics (Fuel); Hospital Staff (Operations and Maintenance); Structural System	Electrical Lifeline; Medical Logistics (Fuel); Hospital Staff (Operations and Maintenance); Structural System	Structural System; Building Utility Systems
INFLUENCE	Hospital Services	Hospital Services	Hospital Services	Hospital Services
MEANS-OBJECTIVES	Minimize damage or loss of architectural elements. Minimize debris.	Minimize service disruptions. Maximize alternate sources of service provision.	Minimize service disruptions (i.e., blackouts and brownouts). Maximize alternate sources of service provision.	Minimize damage or loss of building contents. Minimize debris.
CHARACTERISTICS OF EFFECTIVENESS	Access to Spaces; Availability of Spaces	Flow (volume/time); Pressure; Aesthetic Quality (Odor, Taste, Appearance); Contaminants; Specialized Quality (pH Balance, Ionization)	Current; Voltage; Quality (Continuous Current)	Access to Equipment and Supplies; Availability of Equipment and Supplies

The nonstructural components have intra-system dependencies. For example, lighting relies on the facility's electrical service to function. Many pieces of medical equipment depend on power, water, or medical gases for their operation. The nonstructural subsystems also have dependencies on other systems, both internal and external to the hospital. All of the subsystems are dependent on the structural system, and the building utilities are dependent on lifelines for the product of their service and hospital staff for operations and maintenance.

To achieve the availability of the nonstructural system, we must minimize damage and loss, minimize service disruptions, maximize alternative sources of service provision, and minimize debris. Toward those ends, there are characteristics of the components from which we can measure our effectiveness toward achieving the objectives. The characteristics identified in the table are conceptual and representative rather than comprehensive.

The objectives can also be depicted in a more traditional means-objectives network. Figure 4.1 shows the means-objectives for the three nonstructural subsystems and the lower-level objectives that support the achievement of the higher-level objectives.

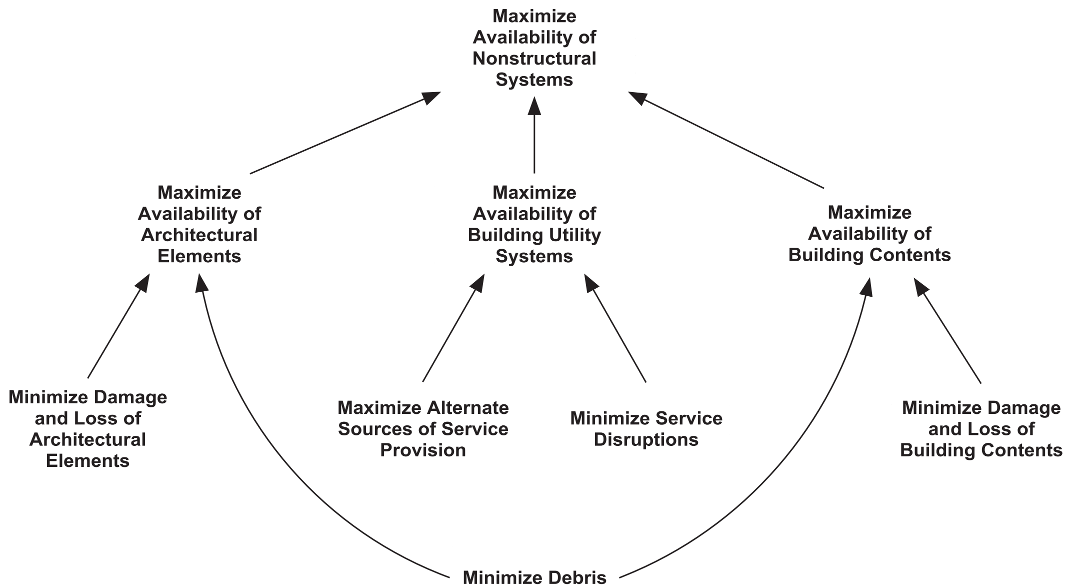

Figure 4.1: Means-Objectives Network for Nonstructural System

4.4.1.2 Influence Diagram

After identifying the systems, components, dependencies, influences, and objectives, I developed the influence diagram. I created the elements, arranged them hierarchically so that components were nested within systems, and added the arcs indicating the influences between elements.

All of the elements are depicted as rounded rectangles. Subordinate elements are contained within the boundaries of larger elements. The relationships between elements are shown as arcs with arrowheads indicating the direction of influence. In keeping with the convention associated with influence arcs, the arrowheads only point in one direction (Clemen, 1996). No influence arcs have arrowheads at both ends of the line.

Developing the influence diagrams was an iterative process. It started at a high level. The internal systems necessary for the functioning of a hospital can be summarized in three broad areas: structural, nonstructural, and functional (World Health Organization, 2010), which are shown in Figure 4.2. Structural systems provide the physical facility. Nonstructural systems provide the physical environment, the necessary utilities, and other essential support. Functional systems consist of organizational, procedural, and resource elements. The nonstructural and functional systems depend on various external systems for their successful operation.

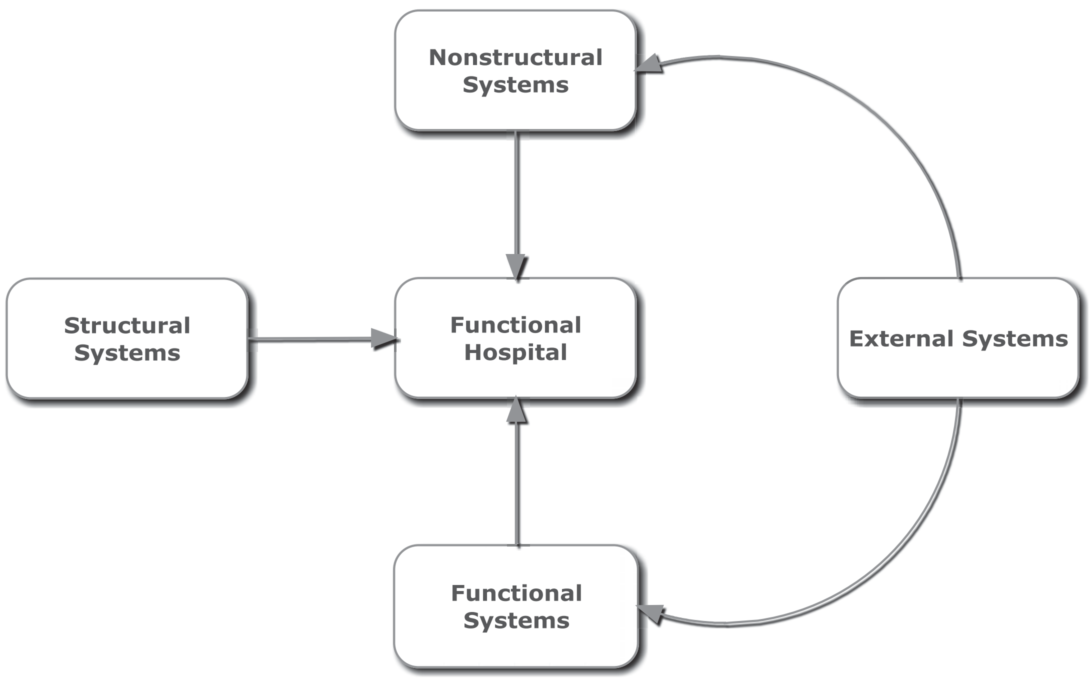

Figure 4.2: System Influences on Hospital Functionality

As the diagram development progressed, systems were refined and components were added. Figure 4.3 is a simplistic representation of how some of these systems can be broken down even farther to provide a more complete understanding of the relationships and interactions of the operational elements necessary to maintain the provision of health care. This is an early step in developing an influence diagram depicting greater specificity of elements and influences.

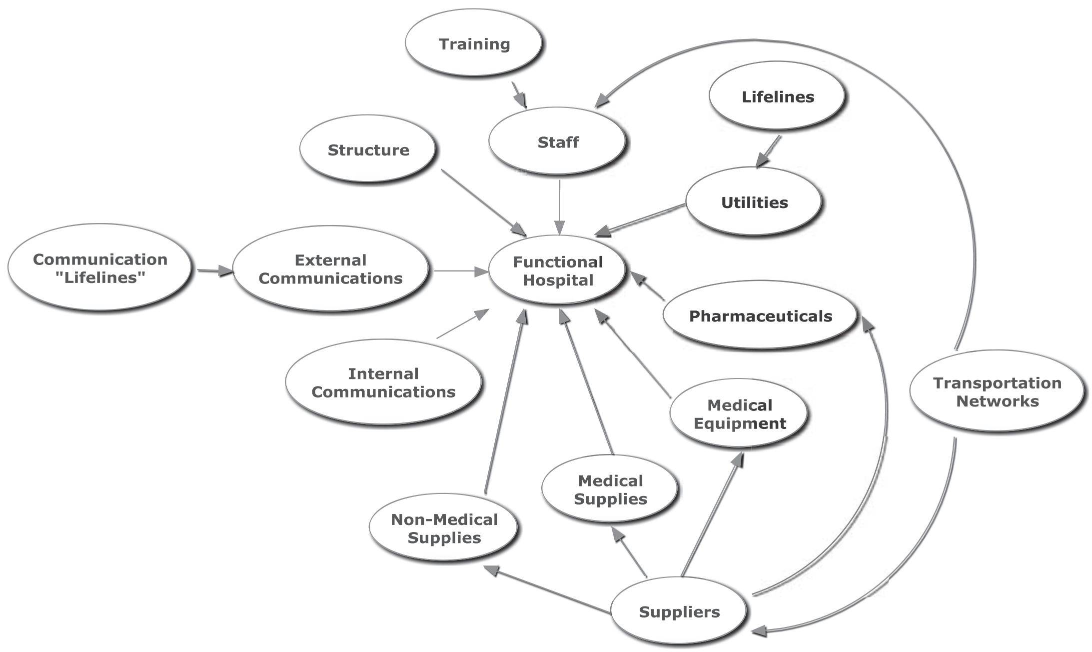

Figure 4.3: Influences on Hospital Functionality

Ultimately, three scales of influence diagram were developed for this project: System, Spaghetti, and Service. Figure 4.4, the System Diagram, is a summary model that depicts the systems and the major influences that exist between them. The systems are farther divided into those that are internal to the hospital and those that are external. The internal systems are contained within the rounded rectangle titled, “Functional Hospital.” Ultimately, all of these systems enable the hospital to support community disaster response.

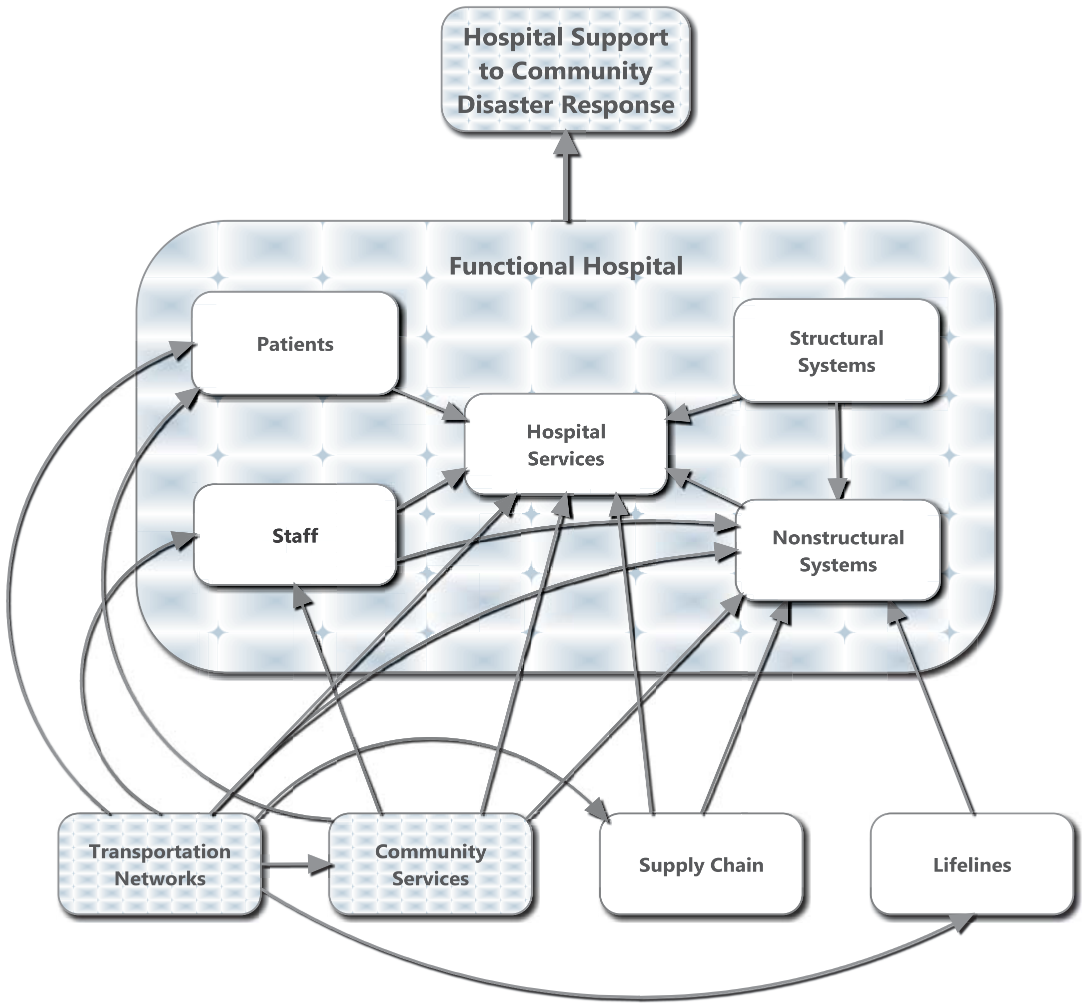

Figure 4.4: System Diagram of Hospital Functionality

The Spaghetti Diagram is the most complex and detailed of the models. It is also the largest model. Because of its size, the Spaghetti Diagram is not included in the text of this dissertation. It can be found on the Internet at the following link: http://udspace.udel.edu/handle/19716/12903. The Spaghetti Diagram is comprised of eight systems that are further divided into subsystems, units, and parts (Perrow, 1984). Each of these is represented by a rounded rectangle with smaller elements nested inside larger elements. The elements representing parts are contained with the elements representing units. This convention continues to the top level were all subordinate elements are shown within the system rectangle. Influence arcs link the elements in which one is dependent on the other for service or function. The Spaghetti Diagram does not reflect the influences that exist within the systems, except for lifelines. Only the influences between systems are shown. The intra-system arcs are omitted because it is assumed the units and parts identified within the systems and subsystems are representative rather than comprehensive.

To understand the intra-system relationships, we must look to the service diagram. Figure 4.5, the version of the model included in this dissertation, shows the role water plays in maintaining a functional hospital. From left to right, the diagram depicts the influences between units in the water lifeline and hospital water utility system to the hospital services. In this case, the units and influences create a line diagram of water service from the source to the point of use.

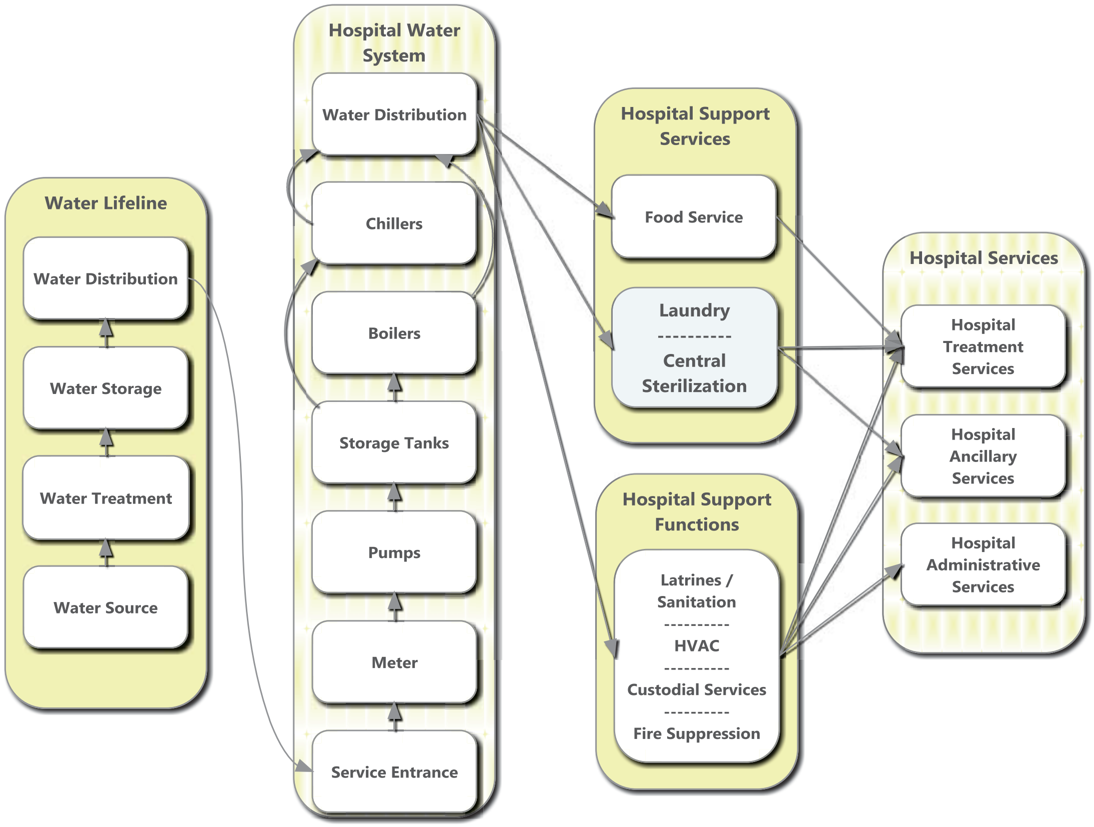

Figure 4.5: Influence of Water Systems on Hospital Functionality

4.4.2 Operationalizing the Model

The influence diagram is intended to support a more comprehensive understanding of the internal and external systems upon which the hospital depends to remain functional and delivery effective health care. This tool benefits us in a number of ways. It increases the breadth and depth of the view we have of hospital and hospital dependent systems. The diagram also provides users with a common picture of those systems that can be used by people of different backgrounds and expertise. Finally, the model is both scalable and modifiable.

4.4.2.1 Breadth of Understanding

The influence diagram offers breadth to our understanding of the myriad elements that play a part in enabling a hospital to deliver health care. It helps us to think about the external systems and components that exist outside of the facility and medical campus but upon which the hospital is dependent. Its inclusiveness brings attention to elements, connections, and relationships that are otherwise hidden or not obvious.

While I attempted to include key systems and components in the model, it is understood that it will never be truly comprehensive or completely represent reality. There is benefit to making the model as comprehensive as possible, but it can always be made more so. Recognizing this incompleteness is important because knowing what we do not know may make us more cautious and deliberate in our planning and design processes.

Thinking beyond our own interactions is important operationally, too. The medical director of an emergency department in a New York hospital described how one or two uninformed people can counteract all of the preparedness actions taken by others for a bioterrorism or hazardous materials event by carelessly contaminating patients, the facility, equipment, and staff members. He explained that during an emergency preparedness exercise,

> We had our own Typhoid Mary, so to speak. One of our patient care technicians . . . managed to walk and contaminate every patient in the entire emergency department, introduced them to everyone, and contaminated, basically, the whole first floor. One person did that.

As a system, all the components of the hospital must be working together. Problems with one key component can cause the whole system to break down.

4.4.2.2 Depth of Understanding

The influence diagram also improves the depth of our understanding of the hospital and the systems on which it depends. Being able to visualize the many components within a system helps us appreciate the complex arrangement of elements and the numerous connections necessary for the continuity of services. It helps people with different duties and responsibilities grasp the inner workings of systems on which they depend but do not have an in-depth understanding.

A respondent to the Hospital Rehabilitation, Impediments, and Incentives study described how the loss of a breaker caused a failure of the emergency power system for one of their most critical buildings.

> We're required to do a special power test where the electricity to the hospital is shut off totally and your emergency generator comes on and they spend about four hours going through the building to make sure that everything that is supposed to be on emergency power is on emergency power and it works. And we lost a rather large breaker in the middle of that, so for about 25 minutes the ICU [Intensive Care Unit] building was totally without power.

This is an example of how the loss of one component can render an entire system inoperable. That loss cascades through the other systems that are dependent upon it.

4.4.2.3 Common Operating Picture

The influence diagrams provide a common view of the system of systems on which hospitals rely. Different people within any given hospital have varying levels of experience, so relying on individual knowledge and experience is problematic. One expert panelist offered that even with his years of experience in hospitals, there are many things that go on that he is not aware of and does not fully understand. In light of this limitation of individual knowledge, the model can be useful for interdisciplinary teams working on health facility planning and design or hazard vulnerability assessments to support a shared understanding of the elements and interactions that need to be considered. It indicates how many points of disruption and failure exist within and between the systems. This enables a better understanding of a hospital's vulnerabilities and improves the identification of opportunities for comprehensive mitigation and preparedness activities. In this way, it supports the development of Hazard Vulnerability Assessments and links those analyses to protective actions. As one expert panelist said,

> To support the community installation, not just to pass The Joint Commission, you really need to look at [hazards, vulnerabilities, and mitigation] from a holistic system of systems perspective.

The need for a common picture of these systems is further supported by the apparent inconsistencies in the quantitative data gathered for the Hospital Rehabilitation, Impediments, and Incentives project. The respondents were asked to rate the importance of hospital utility systems and external lifelines for maintaining hospital operations and functionality during and immediately following a disaster. The results of the quantitative analysis are in Appendix R, Appendix S, and Appendix T. What is interesting is that in some cases the participants rated a building utility much higher or lower in importance than the lifeline that serves it. For example, the water lifeline was rated highest in importance among the seven external lifelines. However, plumbing, which represents the building utility system that supplies water to the hospital’s occupants, ranked sixth among the 13 nonstructural systems studied. Such a discrepancy may indicate that hospital staffs do not fully appreciate the complex arrangements that exist between these internal and external systems.

An expert panelist suggested that while the Spaghetti Diagram does not replace design drawings, it may be easier for non-architects and non-engineers to view and understand the building systems and how they relate to one another. It can serve as a mental tickler during the design or vulnerability analysis processes to help participants maintain a systems view and keep an eye on functionality. Toward that end, a respondent suggested the influence diagram is like a surgical checklist. It serves as a method of checking to make sure the design team has considered all the various functional relationships within and outside the facility. It could help the designers and decision makers walk through systems to ensure they meet the needs of the staff and patients.

The influence diagram can also be a tool that serves to start a discussion between the emergency manager, safety officer, infection control nurse, and others. Ultimately, a multi-disciplinary team working with the support and involvement of the hospital leadership is needed to develop and implement good emergency management plans. The importance of these types of discussions was evident during a focus group for the Hospital Rehabilitation, Impediments, and Incentives Project. The respondents began talking back-and-forth among themselves to describe the hospital facilities and the ages of the various structures. It was evident that each individual had a less complete understanding of the different buildings, the age of each structure, and the facility vulnerabilities than the group as a whole.

4.4.2.4 Scalability

The influence diagram is scalable. Like a map, it can show increasing or decreasing levels of detail to meet the needs of the user. The System Diagram provides a broad, system view of the elements that bear on hospital functionality, but it does not include component-level elements or influences. The Service Diagram depicts detailed information across systems and at the component-level, but it does so within the limits of a particular service or function. The Spaghetti Diagram is the most comprehensive of the models. It includes all of the systems and their components. However, this inclusiveness results in a figure that can most easily be viewed as a poster or projected on a screen. The System and Service Diagrams, on the other hand, can easily fit on a letter-size piece of paper.

Together, the System, Service, and Spaghetti Diagrams allow communities and hospitals to appreciate the relationships between operational and support systems at different scales. This enables planners to anticipate problems at varying levels and supports the development of strategies for addressing their vulnerabilities.

4.4.2.5 Modifiable

The influence diagram is inherently modifiable. The layout can be manipulated to accommodate the user's preferences. Elements and arcs can be added, removed, or changed as knowledge is improved or to meet the needs of the users. For example, if a particular hospital does not use natural gas, that subsystem and all its components can be deleted from the model. Similarly, new systems or components can be added or removed as technology evolves. One of the expert panelists pointed out that the Spaghetti Diagram (as presented in this dissertation) is a good starting point. However, to be used as a tool by hospital staffs, each functional expert could determine what needs to be developed further and identify those subsystems and components that need to be included in their particular model.

4.4.3 A Tool for Depicting Complex Systems

The influence diagram's inclusion in this dissertation is as a tool for depicting the complex arrangement of systems that enable hospitals to function and, ultimately, remain operational so they may support community disaster response. The model shows systems in depth, to the level of individual parts, and broadly, well beyond the four walls of the hospital. The graphic helps establish a common understanding of the medical treatment facility and its dependent systems. That knowledge is a key component in planning and design, particularly when we are concerned about a hospital's ability to survive a disruption.

4.5 Hazard Vulnerability Mitigation Framework

This portion of the dissertation describes the Hazard Vulnerability Mitigation Framework (HVMF), one of the three tools developed for this project. This section describes the framework's structure and how it may be operationalized.

4.5.1 Structure of the Model

The HVMF, depicted in Figure 4.6, is a mental model that provides a structure for thinking about threats, vulnerabilities, and protective actions. The framework is viewed linearly from left to right in six steps, which are represented by the six categories in the framework: hazards, agents and characteristics, exposure, vulnerabilities, consequences, and mitigation and preparedness. First, identify the hazards that threaten their organization. The list should be as comprehensive as possible.

> I think it would be helpful, because frankly the skill set of those people who are doing the [hazard vulnerability analyses] . . . varies greatly, if you had a pick list of [hazards] to pick from.

Appendix V includes hazards identified in the Kaiser Permanente HVA Tool, U.S. Army Public Health Command HVA Tool, and NFPA 1600. Next, consider the agents and characteristics associated with each hazard. These aspects of the event affect the impact it has. Understanding how different hazards, or the same hazard with different characteristics, can impact a system is an important step in the framework. Third, determine how the hospital is exposed to the hazards. This exposure should be viewed in terms of systems, components, interactions, and dependencies. Fourth, use the hazards and exposure to identify the hospital's vulnerabilities. Determine how the organization can be disrupted by the threats. Next, consider the consequences of a disaster event. Identify how it can impact the systems the hospital relies upon for its operation. Finally, identify protective actions that can be taken to avoid or reduce the negative impacts of a disruptive event.

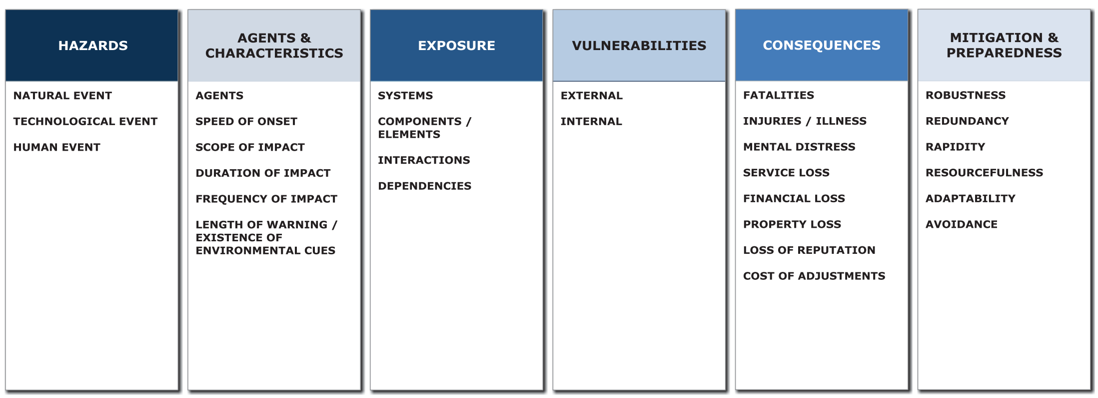

Figure 4.6: Hazard Vulnerability Mitigation Framework

After Hurricane Sandy, New York's Presbyterian Hospital determined that they needed to link their HVA development to pre-disaster mitigation actions. Thus, they developed a "hazardous mitigation assessment program." Thomas Breglia explained,

> We took the hazards listed on the HVA, then went back to facility and clinical operations colleagues and asked them what they considered the most important events and what systems they would be most concerned

about. What began as a total of 31 events and 12 systems was prioritized to 12 events and eight systems (Schaeffer, 2013).

The recognition that the HVA needs to be more closely aligned with protective action is at the heart of the HVMF. The following section provides a description of the six categories and their elements along with definitions for each.

4.5.1.1 Hazards

Hospitals face many threats that can adversely affect their ability to provide adequate patient care. Within the disaster literature, hazards are commonly categorized as natural, technological, or human-induced. In the hospital emergency management literature they are also differentiated as internal or external. This framework relies on the taxonomy from the disaster literature, which was supported by the expert panelists, who agreed these categories appropriately capture the broad spectrum of sources of harm. Table 4.3 identifies the definitions of hazards and their sub-categories.

Table 4.3: Definitions of Hazards

Hazards. Hazards are those events that threaten lives, property, the environment, or organizational operations. They are commonly categorized as natural, technological, or human induced.
Natural. Naturally derived events that threaten lives, property, the environment, or operations. Examples include hurricanes, tornados, floods, and earthquakes.
Technological. Technologically derived events that threaten lives, property, the environment, or operations. Examples include hazardous materials spills, radiation exposure, and utility outages.
Human Induced. Man-made events that threaten lives, property, the environment, or operations. Examples include mass casualty incidents, terrorist attacks, and labor disputes.

In addition to the three sub-categories of hazards, a combination of these threats can result in complex events where multiple causes of disruption compound the effects of the occasion. For example, a train derailment can create a mass casualty event with a range of injury types, plus hazardous material exposure. Such a situation could be attributed to both technological and human-induced causes.

4.5.1.2 Agents and Characteristics

Numerous factors affect the manner in which hazards affect communities, organizations, households, and individuals. Agents are the aspects of a hazard that actually interact with human endeavors and cause the adverse impact. It is not the event we call earthquake that causes the disaster but the effect of the ground shaking. Similarly, it is the water, in the form of rain and storm surge, and wind that causes the damage from hurricanes.

Additionally, five characteristics of these hazards affect the magnitude of the disruption: speed of onset, scope of impact, duration of impact, frequency of impact, and length of warning along with the existence of environmental cues (Lindell, 1994). While it is easy to recognize characteristic differences between types of hazards, we should also not lose sight of the fact that the same hazard can have significantly different characteristics and widely divergent effects. The differences between Category 1 and Category 2 hurricanes can be more than wind speed. Similarly, two Category 3 hurricanes with similar wind speeds may be drastically different in other characteristics.

When Hurricane Sandy struck the New Jersey coast on 29 October 2012, it was only a Category 1 storm. However, it was also the largest Atlantic Ocean hurricane on record (National Oceanic and Atmospheric Administration, 2012). Its size, timing, and trajectory contributed to its creating record storm surge in Lower Manhattan, leading to the closure of six hospitals and 26 long term care facilities in the New York City metro area, and necessitating the evacuation of approximately 6,500 patients (City of New York, 2013).

Table 4.4 identifies the definitions of hazard agents and characteristics.

Table 4.4: Definitions of Agents and Hazard Characteristics

Agents and Characteristics. Agents and characteristics are those aspects of a hazard that affect its impact on a community, organization, household, or individual. Even for the same type of hazard, differences in characteristics can result in differences in impacts.
Agent. The element specifically responsible for causing a disruption. For example, the agent responsible for causing flood damage is water. The agents associated with a hurricane are water, in the form of rain and storm surge, and wind.
Speed of Onset. A measure of the time between awareness of a specific hazardous event and its impact.
Scope of Impact. A measure of the scale of a hazardous event. It may be measured in terms of geography or the range and depth of activities affected.
Duration of Impact. A measure of the time that the hazard causes disruption. The length of time necessary to recover from the disruption is an element of this measure.
Frequency of Impact. A measure of the regularity of a hazard's disruptive events.
Length of Warning / Existence of Environmental Cues. A measure of the time that individuals are forewarned about a disruptive event. Environmental cues serve as an indicator.

4.5.1.3 Exposure

The disaster events that threaten hospitals can occur internally or externally to the facility. All of the systems upon which the hospital is reliant can be affected and, thus, negatively impact the delivery of health care. Having a comprehensive understanding of these systems, their components, and the relationships between them is critical to understanding all of the ways in which hospitals are exposed to hazards. The influence diagram is a tool that can help hospital staff members and emergency manager's view how those systems are exposed to hazards, which becomes the basis for understanding vulnerabilities.

Table 4.5 identifies the definitions of exposure and the systems, elements, and relationships that can be affected by hazards.

Table 4.5: Definitions of Exposure

Exposure. Exposure is the possibility that a particular system, component, element, or interaction will be affected by a hazard.
Systems. An assemblage of interacting, interrelated, or interdependent components or elements working together to form a unified whole. For example, building utility systems in a hospital are composed of many components that are connected to one another and must work together to deliver a given service.
Components and Elements. The subordinate parts of a system necessary for its functioning. For example, boilers and chillers are components of an HVAC system. However, each of these components is also made up of sub-components necessary for their operation.
Interactions. The connections or influence systems, components, elements, or other units of analysis have on each other.
Dependencies. To be partially or entirely reliant upon another for some good or service. Systems and their components are frequently dependent on other systems and components for their function. These relationships create coupling such that a disruption in one system can cause a disruption in another system. This can result in cascading failures.

4.5.1.4 Vulnerabilities

Vulnerabilities are the predisposition of systems, components, elements, or other units of analysis to be negatively impacted by a disruptive event. In hospitals, they are commonly categorized as external or internal to the facility. Vulnerabilities may be best understood in terms of the characteristics of effectiveness identified in the influence diagram's Table of Objectives, which can be found in Appendix U. As an example, the disruption of a hospital's internal electrical system could be the result of degradation in current, voltage, or quality (continuous current). Any of these would have second and third order effects on the functioning of hospital infrastructure and equipment, which would negatively impact the delivery of health care.

Table 4.6 identifies the definitions for vulnerabilities and its sub-categories.

Table 4.6: Definitions of Vulnerabilities

Vulnerabilities. Vulnerabilities are the predisposition of systems, components, elements, or other units of analysis to be negatively impacted by a disruptive event. In hospitals, they are commonly categorized as external or internal.
External. The predisposition of systems, elements, or other units of analysis outside the hospital to be negatively impacted by an event.
Internal. The predisposition of systems, elements, or other units of analysis inside the hospital or a part of the hospital to be negatively impacted by an event.

4.5.1.5 Consequences

Disaster events can impact communities, organizations, households, and individuals in a number of ways. People's health can be affected by injury, illness, or mental distress. Physical injuries or illnesses may be sufficiently severe to cause death. Additionally, service, financial, and property losses can occur during disasters. These may be caused by the initial disruption or can be the result of response and recovery actions. While somewhat intangible, a loss of reputation can occur that results in a loss of revenue or future opportunities. For hospitals, patients and staff may not seek out a particular hospital for care or employment. Finally, the cost of adjustments associated with recovery or mitigation and preparedness for future events is also considered a consequence of a disaster event.

Table 4.7 identifies the definitions for consequences and the seven types of impacts identified in the framework.

Table 4.7: Definitions of Consequences

Consequences. Consequences are the resulting impacts of hazards on people, property, the environment, and operations. These are sometimes referred to as "costs" of hazards.
Fatality. Loss of life (mortality).
Injury or Illness. Harm to an individual (morbidity).
Mental Distress. Mental damage or suffering.
Service Loss. The loss, disruption, or degradation of elements, systems, or other units of analysis.
Financial Loss. The loss of money associated with a disaster or disruption and the following recovery.
Property Loss. The physical loss of property and material due to disasters or disruptions.
Loss of Reputation. The loss of credibility and trust associated with being unable to meet the needs of customers during a disaster or disruption. This may result in additional financial losses or missed opportunities if future customers or potential staff members do not seek out the organization for services or employment.
Cost of Adjustments. Costs in terms of time, effort, and money associated with post-disaster adjustments necessary for recovery, mitigation, and preparedness for future disruptive events.

4.5.1.6 Mitigation and Preparedness

Protective actions are intended to eliminate or reduce the adverse effects of disaster events. They can be understood in terms of six characteristics: robustness, redundancy, rapidity, resourcefulness, adaptability, and avoidance. For this framework, robustness, redundancy, rapidity, and resourcefulness are drawn from the engineering literature on resilience (Bruneau et al., 2003) although the concepts are not fundamentally new. Adaptability comes from ecology (Turner et al., 2003). Avoidance is grounded in planning concepts, like zoning, which seek to separate incompatible uses and avoid foreseeable property losses.

While the six characteristics are drawn from a variety of fields of study, and five of them come from the resilience literature, they are all applicable to the ways in which we understand protective action, particularly in terms of mitigation and preparedness. Table 4.8 identifies the definitions for mitigation and preparedness and the six characterizations of protective action included in the framework.

Table 4.8: Definitions of Mitigation and Preparedness

Mitigation and Preparedness. Mitigation and preparedness strategies and actions are those employed to avoid or reduce negative consequences from disruptive events.
Robustness. "Strength or the ability of elements, systems, and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function." (Bruneau et al., 2003)
Redundancy. "The extent to which elements, systems, or other units of analysis exist that are substitutable, i.e., capable of satisfying functional requirements in the event of disruption, degradation, or loss of functionality." (Bruneau et al., 2003)
Rapidity. "The capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption." (Bruneau et al., 2003)
Resourcefulness. "The capacity to identify problems, establish priorities, and mobilize resources when conditions exist that threaten to disrupt some element, system, or other unit of analysis; resourcefulness can be further conceptionalized as consisting of the ability to apply material (i.e., monetary, physical, technological, and informational) and human resources to meet established priorities and achieve goals." (Bruneau et al., 2003)
Adaptability. The capacity to learn from disruptions and make structural or behavioral adjustments to reduce or eliminate the impacts of future disruptions.
Avoidance. The ability to prevent a particular hazard, exposure, or consequence from affecting an element, system, or other unit of analysis.

Embedded in the concepts of robustness and redundancy is the idea that effectiveness is necessary for continuous operations while efficiency is a liability. Fisher (2013) addressed this idea when he co-opted the term "fracture-critical" from bridge design and construction where it is used to describe how the failure of a fracture-critical member is expected to result in the failure of the entire structure. He argues that a design is fracture-critical, rather than simply flawed, if the results of its failure are catastrophic. That is to say the impacts are much greater than anyone foresaw and extend well beyond the immediate failure. Fisher identifies four key characteristics of fracture-critical designs. First, they lack redundancy. Next, the interconnectedness of the components and the efficiency of the system increase the possibility of cascading failure. Finally, the systems are sensitive to exponential stress. Once that stress rapidly increases, it is almost inevitable that the systems will suddenly collapse. The characteristics of mitigation and preparedness identified in this framework help planners, designers, and decision makers think about their systems and the vulnerabilities in those systems in a manner that avoids or reduces the impacts of disruptions. Applying this way of thinking to hospitals can increase their survivability. One of the expert panelists pointed out that if all government medical record systems are compatible or rely on the same system, it is possible they would all be vulnerable to the same attack. The efficiency gained by having these large systems talk to one another could increase their vulnerability to widespread disruption.

City planners implement Euclidean zoning to separate incompatible uses. This approach is applied to avoid conflicts that negatively affect the health, safety, and welfare of citizens. Fire protection engineers use a different type of separation, referred to as zones, to limit the spread of smoke and fire within a building and between buildings through the use of dampers in HVAC ductwork and fire rated partitions and doors. Electrical distribution and HVAC systems are zoned to improve their efficiency. An engineer studying the relationship between resilience and sustainability suggested that the use of valves in building water distribution networks may allow low priority areas to be closed from the network in order to direct water service to critical care areas during service interruptions. Dr. Anthony Shorris, from NYU Langone Medical Center, described how storm surge from Hurricane Sandy was able to flood the basements of multiple buildings because those buildings were connected below ground (Alphonse, 2013). It is possible that compartmentalizing the basements, like on a ship, may have reduced the scale of the damage. The University of Texas Medical Branch (UTMB) at Galveston is applying a zoned approach to their buildings by separating the utility systems on the ground floors from the upper floors. They are also putting less critical functions on the first floors (LeBlanc, 2013).

4.5.2 Operationalizing the Model

In its present form, the HVMF is not designed or intended to replace existing HVA tools. It supports a way of thinking, not a method for documenting analysis. Its focus is identification rather than prioritization. The model supports an expanded and more nuanced understanding of threats and vulnerabilities to enable the identification of protective actions. The framework makes the link from hazards and vulnerabilities to mitigation and preparedness more explicit.

To be operationalized, the framework faces several opportunities and challenges. The model is scalable and modifiable, which is necessary for it to be adapted into a tool supporting analysis. The framework supports a possibilistic approach to risk that is different than the probabilistic tool so widely adopted in the United States. The scope of the framework is supportive of analysis needed during the planning and design of hospital capital improvement projects, in addition to the planning of operational emergency management. Despite these opportunities, advancing the model to an operational tool is fraught with challenges.

4.5.2.1 Scalable and Modifiable

The framework is scalable and modifiable, but not in the same manner as the influence diagram. The categories, sub-categories, and characteristics may be further divided, which will require new definitions to be developed. Examples can be identified to represent the various elements. Appendix V provides examples of how the framework can be further developed to provide greater depth.

4.5.2.2 Possibilistic Approach

Risk analysis supports decision making under uncertainty. This is particularly useful when leaders are trying to prioritize the application of limited resources to a clearly defined problem. However, this approach tends to focus attention on the most likely events and the most destructive events. Disasters, by their nature, are low probability, high consequence events (Clarke, 2006). Trying to parse out the difference between multiple, low probability events is difficult. The HVMF focuses on possibilities instead of probabilities. Rather than emphasizing the likelihood of a particular event, it seeks to identify possible events. Toward that end, comprehensiveness is desirable.

Some might argue that focusing on possibilities leads to wasting effort on more outlandish threats, like asteroid strikes or electromagnetic pulses from outer space. The probability of these types of events is, clearly, extremely low. While a small number of people are likely considering the consequences of such impacts, I doubt those people are health care emergency managers or hospital owners.

Thinking in a possibilistic manner does not force one to withhold judgment or abandon reason. Instead, it broadens the view one takes of hazards, which similarly broadens one's understanding of exposure and vulnerability. This leads to greater knowledge of possible consequences. Combined, that supports more informed decision making with regard to protective actions.

Resources are still limited and priorities still need to be made. The possibilistic approach leaves decision makers with a more complex and complete understanding of their residual risk than if they only focus on the most probable threats. Greater knowledge of consequences resulting from a broad range of hazards also offers opportunities to identify mitigation and preparedness actions with benefits against many disruptive events. This idea is at the heart of the all-hazards approach to emergency management.

4.5.2.3 Linking Planning and Design to Operations

As a mental model, the HVMF can support analysis for both planning and design of health care infrastructure and hospital emergency planning. The expert panelists agreed we need to more closely align HVA's for planning and design with HVA's for operational hospitals. In both cases, the HVA's should be developed by interdisciplinary teams of stakeholders and experts. The teams should include hospital staff and community officials responsible for emergency management, planning, and public health.

If the HVA developed during the planning of a new hospital includes a multi-disciplinary team of health care providers, health care supporters and administrators, architects, engineers, master planners, and emergency managers, the HVA will look at more than the natural and community-related technological and human-induced hazards that threaten the hospital. It will also consider organizational or hospital-specific threats. If the community master planner conducts the HVA alone, his focus and views will be the only ones analyzed. One of the expert panelists said that he was involved as a hospital representative during the planning and design of a major addition to a large military hospital. He knows an HVA was done as part of the planning, but he does not think he ever saw it.

4.5.2.4 Challenges

Operationalizing the framework so that it can support hazard vulnerability analysis will be challenging. (A step in that direction is to identify as many examples as possible of the characteristics and elements within the six categories. Identifying as many hazards as possible within the three subcategories is an example. The Kaiser-Permanente HVA Tool and NFPA 1600 both have extensive lists of hazards that can be used for this purpose. Relying on the influence diagram to determine exposures and the table of objectives to qualify vulnerabilities may be beneficial, also.

The expert panelists agreed that if the HVMF is to be used operationally, it must not be onerous. It has to be easy to use and should be intuitive. Hospitals are currently meeting The Joint Commission emergency management standards and other regulatory requirements with the tools and knowledge they have today. Thus, why should they expend any additional effort on another approach? McGlown (2001, p. 92) says, "If disaster planning is performed simply to meet regulatory requirements, the level of planning and preparation likely will be inadequate." However, that may not hold sway in a resource constrained environment where emergency management responsibilities are frequently an additional duty. One respondent suggested a menu-based tool that allows users to make selections within the categories and have the computer generate risk values that would allow the users to focus their energies on the development of mitigation strategies.

4.5.3 A Framework for Recognizing Risk and its Implications

The HVMF is a more comprehensive model than others that have been applied to hospitals. It combines approaches to risk from multiple disciplines (e.g., social sciences, engineering, economics, etc.) and applies them to the problem of risks faced by hospitals. The framework supports an improved understanding of the hazards that threaten our hospitals, the ways in which we are vulnerable to those hazards, the potential impacts of disastrous events, and actions we can take to avoid or lessen those impacts. Improvements to the existing standard of practice include clearer definitions of terms and measures, inclusion of essential elements for the provision of health care, the exposure of those essential elements to threats, and the identification of risk reduction measures to further reduce residual risk. The HVMF links hazards and vulnerabilities to consequences and mitigation. Rather than merely identifying risk, like an HVA, it seeks to help us think about risk reduction.

4.6 Optimization Model

While the influence diagram and HVMF are important for understanding the complexities of hospital systems and the risks hospitals face, their structures are theoretical and rely on qualitative representation. The interactions of systems, hospital vulnerabilities, and the consequences of disasters can be considered quantitatively, also. One approach is the development of an optimization model as a way of thinking about how hospital systems interact to maintain organizational functionality. The loss of one system can affect many others. If the disruption is significant, or the dependencies numerous on the disrupted system, the hospital may cease to be capable of maintaining an appropriate health care environment. If the rapid restoration of the disrupted system is not possible, or an alternate method of service delivery is not implemented, the complete evacuation of the facility may be necessary.

The purpose of the model is not to recommend a course of action. Rather, it demonstrates the challenges associated with understanding complex events. While it helps us see the relative values of some variables that affect decision making under uncertainty, it also shows the difficulty of capturing and quantifying all relevant variables in a decision problem. The lesson is that the model's importance is greater as a tool for understanding the problem than recommending a solution.

Archibald et al. (2012) developed this optimization model that considers the effect on health care operations of an extended loss (more than 96 hours) of the water supply lifeline to a hospital in a metropolitan area in the United States during a disaster. The analysis is intended to help hospital and utility decision makers, elected officials, and emergency response coordinators understand the risk to a hospital and health care from an extended water outage during a disaster event. Specifically, the analysis assists decision makers in the determination of whether to adjust the scope of a hospital's medical and support operations following a major disruption. The alternative response strategies considered include closure of the hospital, reduction in the scope of medical services, reduction in the scope of hospital support services, and procuring water to maintain the full operations of the hospital. The model relies on patient, service, and equipment data to estimate water demand under different service provision scenarios. Based on these demand variables and the cost and availability of water, the model identified the lowest cost alternatives under hundreds of scenarios. The results of the simulations show the frequency and range of costs, the frequency with which water demand exceeds supply, and the impact of outage duration on costs.

The sensitivity analysis allowed us to examine the relationships between cost, the number of patients, and the length of the outage.

As prepared, the model is driven by financial considerations. Adding concerns about morbidity and mortality could improve the comprehensiveness of the model. However, as described in the section of the literature review describing injuries and fatalities associated with evacuations, consistent planning factors for morbidity and mortality associated with hospital evacuation are difficult to find. It is possible that the risk of increased patient morbidity and mortality associated with hospital evacuations may be overstated. If that is true, financial considerations, which include the organizational disruption associated with an evacuation, may be more influential factors in decision making.

The optimization model is included here to illustrate the quantification of the consequences of failure. It provides a scenario depicting the essential role nonstructural systems play in hospital functionality and how disruptions may affect decision making. The system dependencies and vulnerabilities are informed by the HVMF, which helps the model provide a case in which system failures put hospital operations at risk and force difficult decisions that can affect patient safety, continuity of care, and an organization's financial well-being. The model demonstrates how a flexible, scenario based tool can influence the manner in which hospital decision makers view hazards, vulnerabilities, capabilities, and mitigation strategies in order to better understand the implications and benefits of risk reduction investments. Specifically, the model shows the close relationship between water and those services and functions that depend on it. The multi-order effects of an outage are presented in the courses of action and the scenarios.

Figure 4.7 is an influence diagram depicting the elements and relationships necessary for the provision of water in support of health care. The model shows how the water lifeline is connected to the hospital's water utility system in direct support of hospital services and support functions. The left side of the Service Diagram depicts the water lifeline and hospital water system along with their major components. It shows the general path water takes from its source to its point of use in the facility. From there, the relationships to hospital services and support functions are identified on the right side of the diagram. This model clearly indicates the large role water has in the delivery of health care. It also hints at the complexity of the delivery system. Additional details about that complexity could be provided by breaking the components down farther and showing the subsystems, units, and parts responsible for getting water to the end user. As depicted, the diagram is not comprehensive, but it identifies the systems, components, and services that are considered in the optimization model.

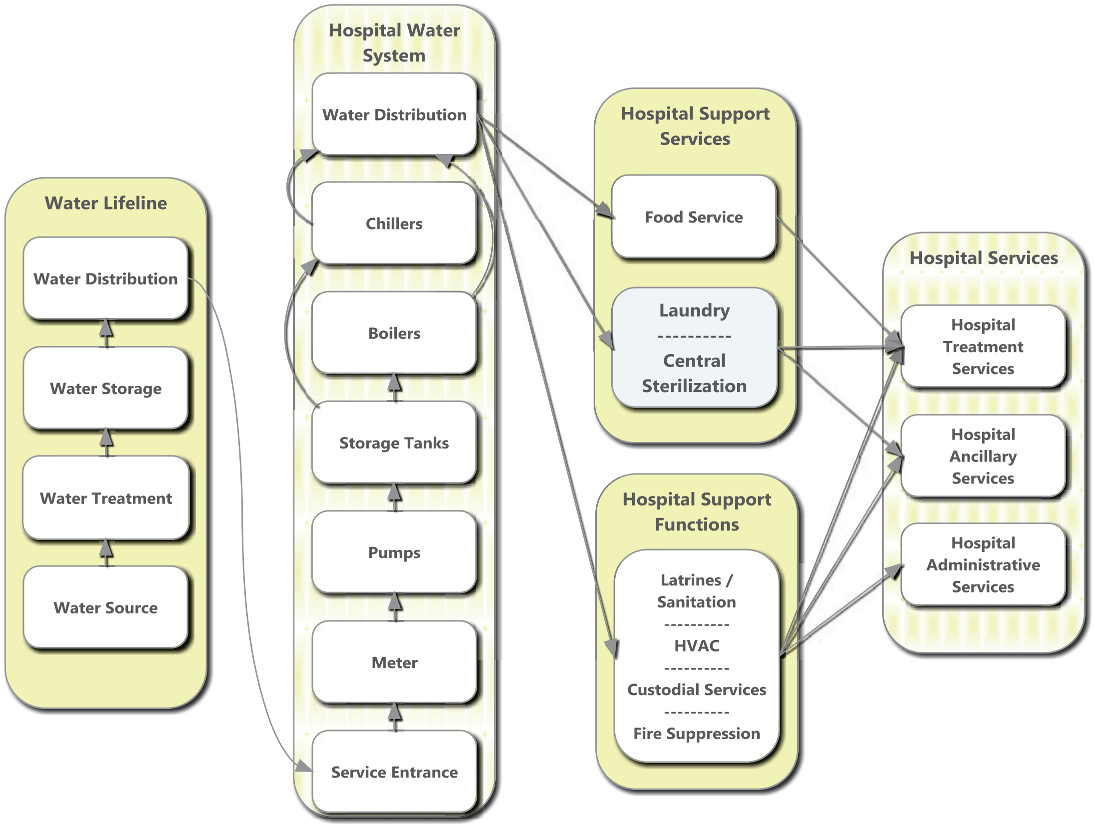

Figure 4.7: Water Service Diagram

4.6.1 Risk and Scope of the Analysis

This analysis considers the effect on health care operations of an extended loss (more than 96 hours) of the water supply lifeline to a hospital in a metropolitan area of the United States during a disaster. It is intended to help hospital and utility decision makers, elected officials, and emergency response coordinators understand the risk to a hospital and health care from an extended water outage during a disaster event. Specifically, the analysis will assist decision makers in the determination of whether to adjust the scope of a hospital's medical and support operations following a disaster event. The alternative response strategies considered include, closure of the hospital, reduction in scope of medical services, reduction in scope of hospital support services, and procuring water to maintain the full operations of the hospital.

4.6.2 Scenario

The following scenario is hypothetical and is intended to establish the basis from which the optimization model is created. Where possible, the scenario is based on real places and real organizations. For example, the Memphis Veterans Affairs Medical Center is an actual hospital in downtown Memphis. The earthquake and the related disruptions are representative of a possible disaster in the City of Memphis.

At 10:17 a.m. on a cool spring day in early April, a magnitude 7.6 earthquake struck the New Madrid fault with an epicenter near Dyersburg, Tennessee, approximately 75 miles northeast of Memphis. Based upon the severity of the shaking, a Modified Mercalli Intensity of VIII was assigned to downtown Memphis. Unreinforced masonry buildings collapsed and some houses were knocked off their foundations. The Hernando-DeSoto Bridge (I-40) and the Harahan Bridge (I-55), both of which link Tennessee and Arkansas across the Mississippi River, were damaged during the earthquake. Engineers from the Department of Transportation estimated both bridges would be closed to traffic for at least ten days.

All 20 of the hospitals in the Memphis Metropolitan Area sustained some damage from the earthquake. Most of the damage was non-structural (e.g., fallen furniture and equipment, broken windows, etc.). While no hospitals collapsed, the downtown hospitals, and those on the north side of the city, received minor structural damage that required the evacuation of some patients to undamaged portions of the buildings. Electrical and water outages affected all of the hospitals downtown and on the city's north side. Memphis Light, Gas, and Water estimates it will take up to one week to replace broken water pipes serving the hospitals.

4.6.2.1 Memphis Veterans Affairs Medical Center

The Memphis Veterans Affairs Medical Center is located in downtown Memphis in the Medical District. It is a 244-bed tertiary care facility with a staff of 2,029 personnel supporting 196,000 veterans in a 53-county area covering western Tennessee, northern Mississippi, and Northwestern Arkansas. Of the medical center's 244 total beds, 20 beds are in the Intensive Care Unit, 216 beds are in the Med-Surg Wards, and eight beds are in the Post-Anesthesia Care Unit.

When the medical center's construction was completed in 1967, the 805,700 square foot building consisted of a 3-story low rise (552,000 SF) facility with a 15-story tower (253,000 SF) sitting on the middle of the low rise structure. The building's frame is primarily cast-in-place concrete with a mixture of one-way pan joists and two-pan pan (waffle) joists for the floors and roof. Shear walls provide lateral load resistance. The exterior face consists of panels of precast concrete attached to the building's concrete frame (Concrete Drilling and Sawing Association, 2012; Freeman, 2012).

In 1985, the Veterans Administration contracted a feasibility study for seismic modification and ward renovations. A review of the original design package determined that seismic forces were not considered in the structural design. The consulting engineers estimated intense damage to the unimproved hospital at a Modified Mercalli Intensity (MMI) VIII and probable collapse at MMI IX or higher. In the early 2000s, the Veterans Administration contracted the removal of the top six stories of the medical center's tower to improve the building's seismic integrity.

4.6.2.2 Damage to the Medical Center from the Earthquake

At the time of the earthquake, the medical center's in-patient census was 154 (13 patients in the Intensive Care Unit and 141 patients in the Med-Surg Wards). Five of the ICU patients were on life support. Twenty-two of the Med-Surge patients were scheduled to be discharged within the next two days. There were also 2,237 outpatients and visitors present and 1,978 staff members on duty.

The facility lost power and water immediately. Full power was restored within four hours. The utility company estimated it would take up to one week to replace broken water pipes to restore full potable water service to the medical center. The hospital does not have dedicated emergency water storage tanks.

The hospital's facility engineers were able to determine that narrow cracks visible on the exterior concrete panels of the bed tower's north and east faces were not evidence of structural damage. A team of engineers is expected to arrive and inspect the hospital in five days to determine if there is any damage that was not identified by the in-house staff.

4.6.3 Methodology

4.6.3.1 Variables

To reduce the scope of analysis such that it is appropriate for the resources available, the model only includes a limited number of variables that are water demand intensive functions. The medical services that this analysis includes are the intensive care unit and the med-surg wards. The hospital support services included in the analysis are food services, central sterilization, toilet facilities, and heating, ventilation, and air-conditioning (HVAC).

4.6.3.2 Building the Optimization Model

Hospital functions dependent on water, such as food services, sanitary, sterilization, and air conditioning, are inherently vulnerable to a water outage. We defined variables that represent the decisions that hospital management will need to make about how to adapt to a water outage. In our optimization model, we sought decisions that yielded the lowest cost. To model the decisions, we defined variables and specified the variable type and bounds. The costs associated with each of these variables are represented by its coefficient, which is calculated based on both deterministic and stochastic inputs. These calculations will be fully explained later. Table 4.9 illustrates the list of variables of interest according to the scope of this study, which, as described earlier, represent key dimensions when it comes to considering what drives water consumption within the hospital.

Table 4.9: Characterization of Variables

		Variable	**Type**	**Label**	**Bounds**	**Coefficient**
Medical Services	ICU	# of patients to be transferred	Integer	X1	0<=X1<=8 Expecting 8 at the most	Cost per patient (assumes one patient per ambulance)
		# of patients on life support to be transferred.	Integer	X2	X2<=5 Expecting 5 at the most	Cost per patient (assumes one patient per ambulance)
	Medical Surgery	# of patients to be transferred.	Integer	Y1	0<=Y1<=141 Expecting 141 at the most	Cost per patient (assumes one patient per ambulance)
		# of patients to be discharged within two days	Integer	Y2	Y2<=22 Expecting 22 at the most	Cost per patient (assumes one patient per ambulance)

Table 4.9 continued

Support Services	Food Supply	Contract/In House Breakfast	Binary	Z1/Z2	0 or 1	Cost of each breakfast meal/patient contracted
		Contract/In House Lunch	Binary	Z3/Z4	0 or 1	Cost of each lunch meal/patient contracted
		Contract/In House Dinner	Binary	Z5/Z6	0 or 1	Cost of each breakfast meal/patient contracted
	Sterilization	Contract/In House Sterilizatio n	Binary	W1/ W2	0 or 1	Cost of sterilization/day contracted
	HVAC	HVAC at 30%	Binary	V1/V 2	0 or 1	Cost of water usage per day
	Sanitary	Contract Latrines-Red Bag Patients Latrines	Binary	U1/U 2	0 or 1	Cost per latrine contracted

The decisions described in Table 4.9 are represented by 16 variables. These variables can be used to describe many different alternatives by defining the scope of medical and support services. For example, as the water outage takes place, one could establish the following specific alternatives: all patients in the ICU are to be transferred (including those patients on life support), all patients in the med-surg wards should remain, breakfast and lunch should be served in-house while dinner meals should be contracted, sterilization should be contracted, HVAC should work at 100 percent, and sanitary services should be contracted, as well. In sum, if all the alternatives were to be evaluated, all potential combinations of these variables would have to be considered regardless of the parameters used for making the decision on whether or not to transfer patients or contract supportive services.

As a suggestion for concurrently considering all the potential alternatives, an optimization model was built with an objective function to evaluate total additional cost due to the water outage. The objective function is defined as the sum of each of the decision variables and the coefficient representing the cost of that option:

Objective Function:

$$Minimize\ (\sum_{i=1}^{2} K_i X_i + \sum_{i=3}^{4} K_i Y_{(i-2)} + \sum_{i=5}^{10} K_i Z_{(i-4)} + \sum_{i=11}^{12} K_i W_{(i-10)} + \sum_{i=13}^{14} K_i V_{(i-12)} + \sum_{i=15}^{16} K_i U_{(i-14)})$$

Z_2, Z_4, Z_6, W_2, and U_2 represent all the supportive services that would take place in-house otherwise, except for V_2, which represents HVAC at 30 percent.

Where:

Z_1, Z_2, Z_3, Z_4, Z_5, Z_6, W_1, W_2, V_1, V_2, U_1 and U_2 are binary values (0,1).

X_1, X_2, Y_1, Y_2 are integers.

Subject to:

$0 \leq X_1 \leq 8$	No more than 8 non-life support patients can be transferred from the ICU (there were only 8 to begin with).
$0 \leq X_2 \leq 5$	No more than 5 patients on life support can be transferred from the ICU.
$0 \leq Y_1 \leq 141$	No more than 141 patients can be transferred out of Med-Surg.
$Y_2 \leq 22$	No more than 22 patients are ready to be discharged from Med-Surg.
$Z_1 + Z_2 = 1$	Hospital will either contract breakfast service or provide in-house.
$Z_3 + Z_4 = 1$	Hospital will either contract lunch service or provide in-house.
$Z_5 + Z_6 = 1$	Hospital will either contract dinner service or provide in-house.
$W_1 + W_2 = 1$	Hospital will either contract sterilization services or provide in-house.
$V_1 + V_2 = 1$	Hospital will either leave the HVAC operating at 100 percent or reduce the HVAC to 30 percent.
$U_1 + U_2 = 1$	Hospital will either contract sanitation services or provide in-house.

$$(K_{17}Z_2 + K_{18}Z_4 + K_{19}Z_6) * K_{20} + K_{21}W_2 + K_{22}V_2 + K_{23}U_2 < Maximum\ available\ gallons\ (Bulk\ Water).$$

This restriction limits the amount of water that the hospital can import each day.

Where:

$K_{17} = \%\ of\ dining\ water\ spent\ on\ breakfast\ meals.$

$K_{18} = \%\ of\ dining\ water\ spent\ on\ lunch\ meals.$

$K_{19} = \%\ of\ dining\ water\ spent\ on\ dinner\ meals.$

$K_{20} =$ (% of daily water usage on dining)*(Average daily water usage)*(Total number of patients).

$K_{21} =$ Gallons of water used for sterilization.

$K_{22} =$ Gallons of water used for HVAC.

$K_{23} =$ Gallons of water used for bathrooms.

By using the Solver add-in in Microsoft Excel, it was possible to develop an optimization model that minimized the objective function by using the GRG Nonlinear method. After running the optimization model several times in order to test its consistency by varying the coefficients, it was possible to prove that no restriction was ever violated, as well as, obtaining a minimized objective function by suggesting the best values for each of the 16 variables contained in the model.

4.6.3.3 Inputs

The model uses both deterministic values and distributions for inputs. One of the most important inputs is the length of the water outage. This value is modeled as an exponential distribution with a mean of seven because in our scenario the utility gives the hospital an estimate of a seven day outage and the exponential distribution is a good means to model a time period to complete a task such as fixing water distribution lines. Apart from the outage duration, there are three categories of input parameters used by the model. The model accepts inputs about the hospital's initial in-patient population, the costs associated with a water outage and the amount and costs of bulk water that would be required in the event of an outage.

4.6.3.3.1 Patient Population Inputs

The patient population input parameters are shown in Table 4.10.

Table 4.10: Patient Population Parameters

Parameter	Value
Initial ICU Population (total)	13
Initial ICU Population (on life support)	5
Initial Med-Surge Population (total)	141
Initial Med-Surge Population scheduled for discharge two days after the earthquake	22

These values were selected for this specific scenario, and are based on yearly reports that describe this particular hospital's average census, inpatient days and discharges.

4.6.3.3.2 Cost Inputs

For many of the cost parameters we have assumed a fixed cost. This would be reasonable if the hospital has pre-negotiated contracts for emergencies, which we will assume they do. Assuming fixed contract costs for services helps eliminate some of the uncertainty and keeps the problem as simple as possible. Fixed cost input parameters are shown in Table 4.11.

Table 4.11: Cost Parameters (Point Estimates)

Parameter	Value
Cost of catering breakfast (per inpatient)	$5.00
Cost of catering lunch (per inpatient)	$6.50
Cost of catering dinner (per inpatient)	$8.00
Advanced Life Support Transfer (per transfer)	$700.00
Basic Life Support Transfer (per transfer)	$500.00

For other cost parameters we used a uniform distribution. We have done this because we are unsure as to what these services might really cost and each cost has an equal probability of occurring. Because of this uncertainty we have run the simulation using a range of values our research has shown are possible, which are reflected in Table 4.12.

Table 4.12: Cost Parameters (Distribution Estimates)

Parameter	Distribution
Cost of contracting sterilization	Uniform: min = $2,000/day max = $10,000/day
Cost of contracting latrines	Uniform: min = $100/day max = $500/day
Cost of inpatient waste removal	Uniform: min = $5/patient-day max = $50/patient-day

4.6.3.3.3 Bulk Water Usage, Costs and Availability

Hospital management must decide whether to contract external services or to continue to provide services in-house using contracted bulk water. To compare these costs it is necessary to know the amount of water needed to provide in-house services. This amount varies daily and is not well documented or measured. Beyond the quantity of bulk water required, the price for bulk water may also vary. We investigated changes in bulk water costs and accounted for its availability following an earthquake. While bulk water delivery is available in most communities across the country, there are a limited number of suppliers and after an earthquake it may be impossible to deliver all the water a hospital needs due to logistical issues. No data is available as to the quantity of water bulk water available in Memphis. So, we estimated that a hospital would have difficulty accepting more than twenty-four 2,000 gallon trucks a day due to the amount of time it takes for a truck to fill up, travel, and off-load its water at the hospital. Since we were unsure of this quantity, we made a normal distribution of the values. The water parameters are shown in Table 4.13.

Table 4.13: Water Parameters

Parameter	Distribution
Cost of Bulk Water	Uniform: min = $0.01/gal, max = $0.10/gal
Maximum Amount of Bulk Water Available Daily	Normal: mean = 48,000 gal/day, std dev = 10,000
Daily water usage per patient	Normal: mean = 450 gal/patient-day, std dev=120

Table 4.13 continued

Percent of daily water usage used for dining	Deterministic: 9% of daily water usage
Percent of dining water used for breakfast	Deterministic: 25% of daily dining water usage
Percent of dining water used for lunch	Deterministic: 35% of daily dining water usage
Percent of dining water used for dinner	Deterministic: 40% of daily dining water usage
In-house sterilization bulk water needed	Normal: mean = 1133 gal; std dev = 28 gal
Water required for normal bathroom service	Uniform: min = 19,303 gal; max = 83,672 gal
Water Required for 100% HVAC	Uniform: min=10,571 gal; max = 45,821 gal

4.6.3.4 Simulation with Optimization Model

The purpose of running simulations of the optimization model is to identify what decisions are optimal for varied input parameters. We ran the optimization model 500 times using sampled values for the inputs. This was accomplished by varying the input parameters according to specified distributions and running the optimization model for each set of sampled inputs. This allowed us to see what the most optimal decision was given changing inputs.

The simulation was performed using Excel, the Solver add-in, and Visual Basic for Applications in Excel. Inputs for the simulation as seen in Tables 4.10 through 4.13 are placed on a single worksheet. Along with each input, the type of distribution (deterministic, normal, uniform, etc.) and parameters for the distribution (mean, standard deviation, etc.) are specified. A custom-built function in Excel samples values for each parameter according to the appropriate distribution and a random value, which is pulled from a table of random numbers. Each trial has a seed number which represents the row of random numbers used to generate the input parameters. This seed number can be used to re-run a trial manually and create the same results. Using the same set of seed numbers in a simulation allows us to compare multiple simulations using common random numbers.

4.6.3.5 Selected Alternatives Simulation

In the event of an actual earthquake and water outage, hospital management will not know in advance exactly how long a water outage will last. As such they will have to make their decisions based on limited information. The optimization model simulation provides information about what the optimal solution would be if the duration of the water outage and all the other variables were known in the beginning when the decision is made. This simulation models the actions of hospital management by evaluating a given decision against sampled input parameters.

Three simulations of 1,000 runs each were performed to look at the direct costs associated with three selected alternatives against sampled input values. These simulations use common random numbers to sample input values according to the distributions previously described. For these simulations, the decision variables are static as opposed to optimized.

4.6.4 Results

4.6.4.1 Simulation with Optimization Model

The simulation runs of the optimization model provided data as to what decisions are most likely to be optimal in terms of least total cost during a water outage. For each of the 500 sets of sampled input values, the value of each of the decision variables that minimizes costs is determined. As the decision variables are binary (0 or 1), the percentage of data sets for which each outcome realizes the optimal solution (minimum cost) is recorded.

The simulation using the optimization model provides data about which alternatives are optimal more frequently. Figure 4.8 shows how often contracting outside services was selected as opposed to buying and trucking in bulk water to provide services in-house. For example, contracting the provision of lunch is the optimal solution for only 6 percent of the input values.

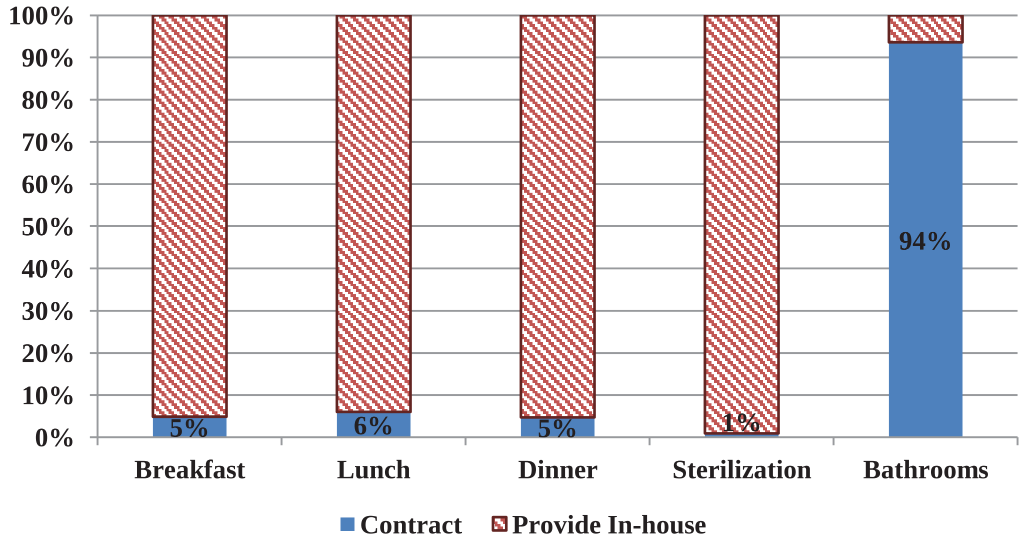

Figure 4.8: Frequency Preference between Buying Bulk Water to Provide Services In-house and Contracting Services

The simulation showed that when possible, trucking in bulk water is often a cost-effective solution to continue in-house dining, sterilization and sanitary services. In situations where there is not enough water to provide all of these services, it is possible to provide some of these in-house and contract others for which there is not enough water. For the range of the cost and water use inputs defined, purchasing bulk water to provide services in-house is almost always the most cost effective solution. However, this is not always possible due to limits in the maximum amount of water that could be trucked in each day. It was found that for dining and sterilization, buying bulk water to continue in-house service was selected much more often than contracting out the service. To provide sanitary services, it was found that contracting portable toilets and hand washing stations was preferred to continuing normal restroom services. This is because restrooms use significantly more water than dining and sterilization. Since, most of the time, there was not enough water to buy in order to provide all services in-house; restrooms are the first to be outsourced due to the large amounts of water they use.

The optimization model also examined how often the hospital should partially or completely close requiring the evacuation of inpatients. Figure 4.9 illustrates how often each section of the hospital was closed based on the 500 runs. The bar labeled “hospital” represents a complete closure of the facility. The other three bars represent closure of specific medical services (i.e., Intensive Care Unit beds, the patients on life support in the ICU, or the medical-surgical ward beds).

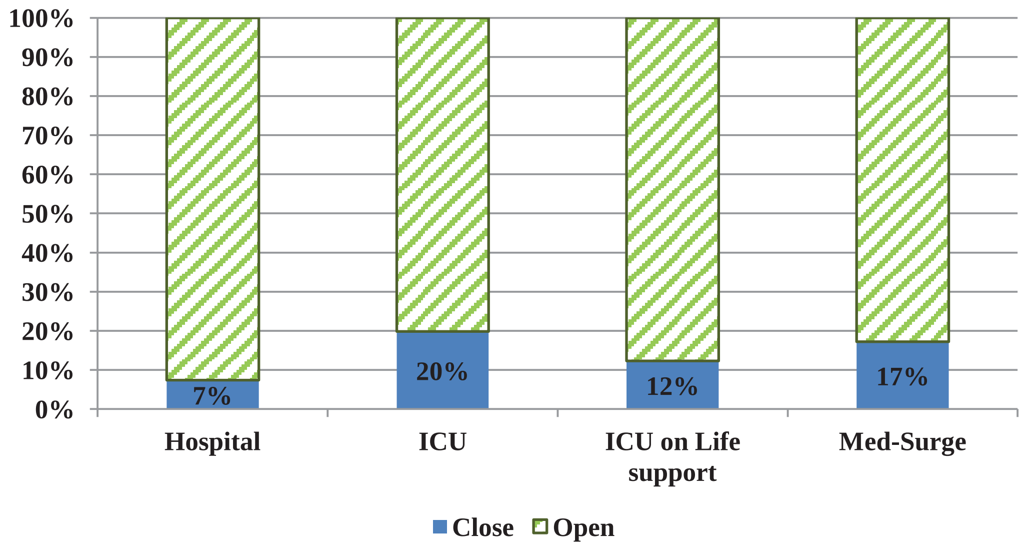

Figure 4.9: Frequency of Preference for Medical Service Closure

The optimization model determined when partial (i.e., ICU beds, ICU life support beds only, or med-surg wards) or full evacuations would be the lowest cost option. In most cases the optimization model recommended leaving the hospital open. Approximately 20 percent of the time it recommended a partial evacuation of inpatients from either the ICU or med-surg wards. The graph above shows the frequency of closures for the 500 runs. In very few cases was a partial evacuation preferred. For cases where water needs were much greater than bulk water delivery availability, or for long outages, the best option is to evacuate the entire hospital. This is a more expensive option and is only necessary when no other option exists or when excess expenses run over approximately $70,000 for the duration of the water outage.

Hospital management may be very concerned that an event such as this will exceed money set aside for emergencies. Using the previously described inputs it was found that the added direct costs due to the water outage will be less than $100,000 for 92 percent of the trials. If the optimal decisions could be made every time, the frequencies of predicted direct costs are depicted in Figure 4.10.

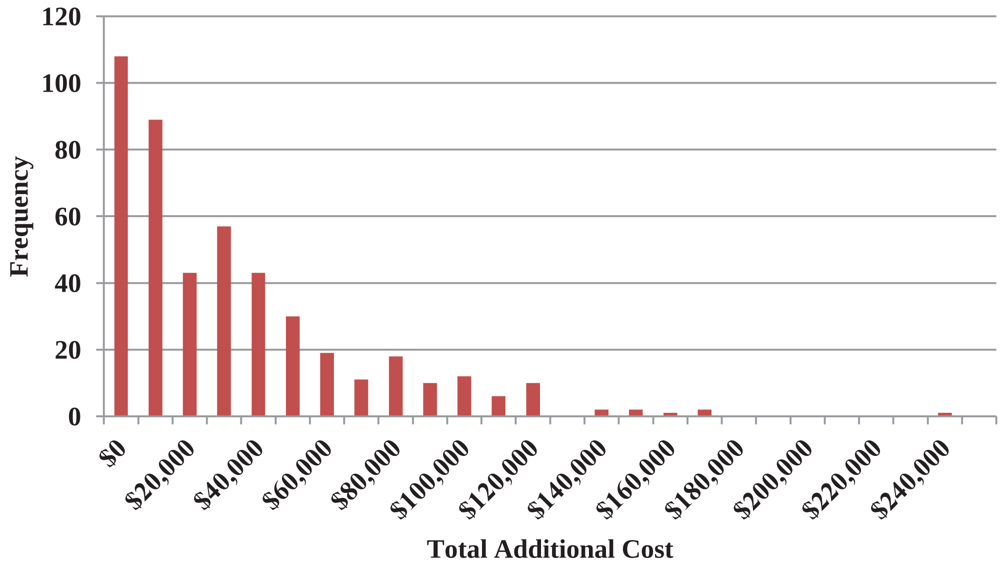

Figure 4.10: Additional Direct Costs from Water Outage

In this case the expected value of the financial risk is $39,328, and the probability that the cost will exceed $100,000 is 8.2 percent. Anticipating the additional costs, as seen in Figure 4.10, would only be possible if hospital management knew the outage duration and every other input from the beginning and was able to optimize to reduce cost. However, since decision-makers will not know the length of the water outage from the beginning, it is unreasonable to expect that they will always select the optimal solution.

4.6.5 Comparison of Alternatives

In practice, hospital management will not be able to select the optimal solution because they will not know everything up front. Instead they must select an alternative and wait to see how everything turns out. The selected alternatives simulation compared three alternatives against 500 sets of input parameters to show the financial risk associated with each alternative. Each of the three alternatives was simulated using random variables reflecting common variable ranges to allow for easier comparison. While there are more than five hundred possible combinations of the decision variables, we have chosen to examine only three courses of action. These three were selected due to their practical significance. We examined the financial risks of remaining open and continuing to provide all services in house, remaining open and providing only dining and sterilization in-house and closing down the entire hospital.

4.6.5.1 Alternative 1: Remain Open, Provide All Services in House

The first alternative examined was the decision to continue medical and support services as usual. This consists of remaining open, not transferring patients, and providing dining, sterilization and sanitary services in-house using contracted bulk water. A graph of the risk profile is shown in Figure 4.11.

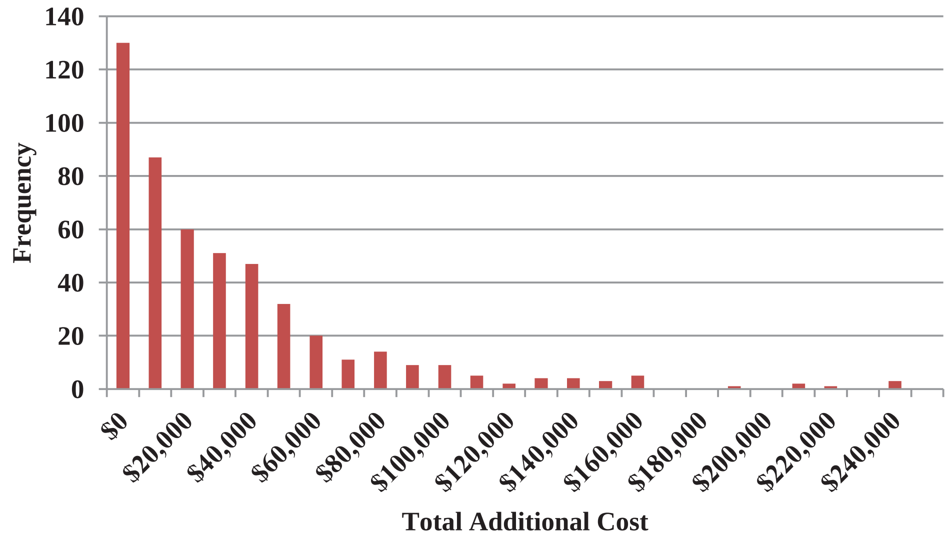

Figure 4.11: Risk Profile for Alternative 1

In this case the expected cost was $38,077 and the risk that it exceeds $100,000 was 7.8 percent. Although this alternative is typically cost effective, this solution is not always possible due to the limited amount of water that the hospital can procure each day. The simulation revealed that, in fact, this option is only possible seven percent of the time due to the limited amount of water that the hospital can purchase each day. The expected cost for remaining open and providing services in house is actually less than that of the optimization model, because this model doesn't always meet the restriction on the maximum amount of bulk water that can be purchased each day.

4.6.5.2 Alternative 2: Remain Open, Contract out sanitation service

When Alternative 1 is not possible due to a limited amount of water to be procured, Alternative 2 can typically be implemented. In this alternative, everything remains open, dining and sterilization are performed in-house, but sanitary services are contracted out by leasing portable toilets and hand washing stations. In addition, in-patient waste will be collected and disposed of through the biomedical waste system. This alternative significantly reduces the amount of water that needs to be purchased, but it is dependent on the availability of portable toilets and hand washing stations. Figure 4.12 shows the risk profile for this option.

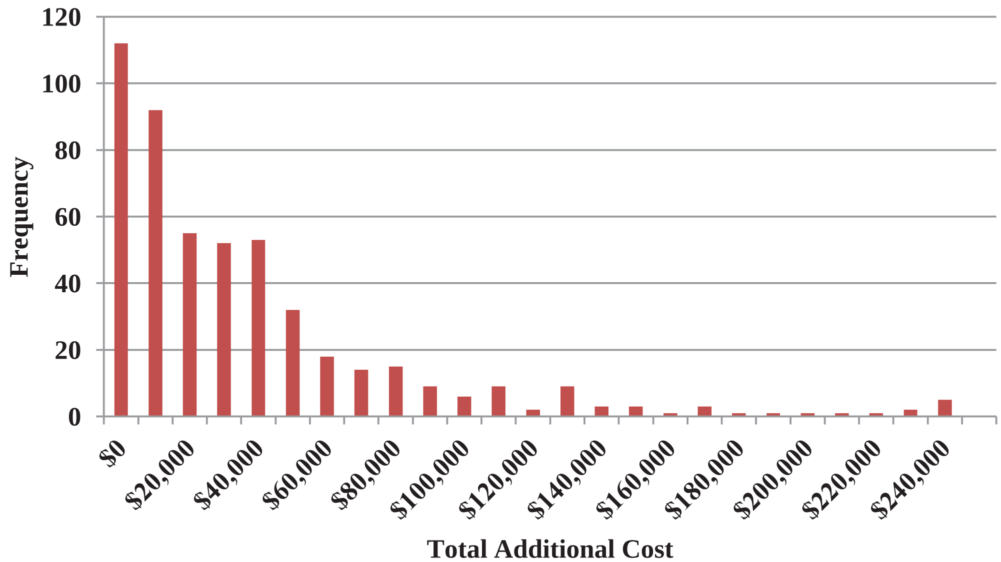

Figure 4.12: Risk Profile for Alternative 2

For this case, the expected cost was $42,320, and there was a 9.6 percent chance that expenses would exceed $100,000. While it is more financially risky than Alternative 1, its demand on bulk water delivery is much lower.

4.6.5.3 Alternative 3: Close Hospital

Another possibility is closing the entire hospital. This would require a large initial cost to evacuate all the patients, but over time it would save money by reducing the need to maintain support services. The risk profile for shutting down the hospital is shown in Figure 4.13.

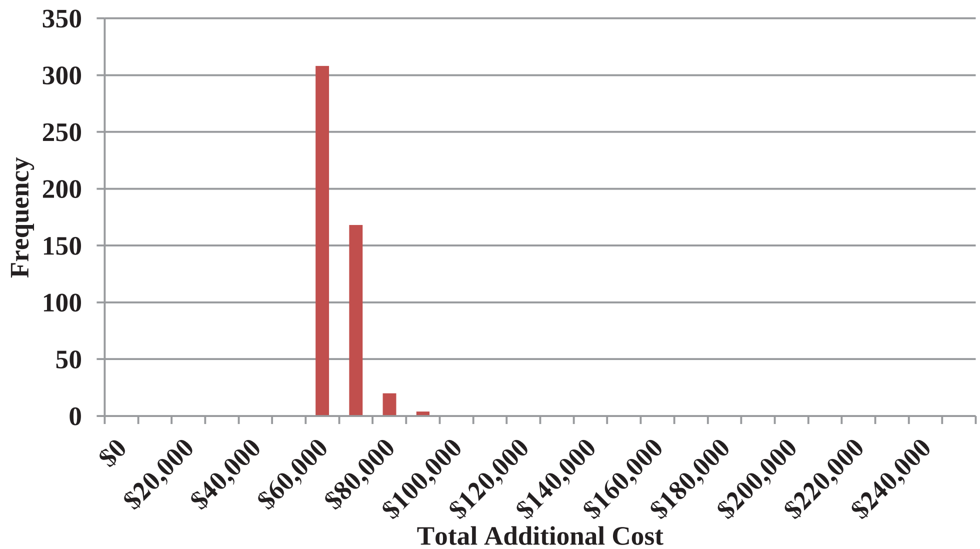

Figure 4.13: Risk Profile for Alternative 3

Immediately closing the entire hospital has a higher expected value of $70,379 and a 0 percent chance that the cost will exceed $100,000. While this option, on average, has a higher cost, it may be beneficial because the possibility of very large costs is eliminated. Although this option is best for reducing uncertainty in the total additional cost, it may increase the health risks to all of the patients, who are being transported from one hospital to another.

4.6.6 Sensitivity Analysis

The setup of the simulation made sensitivity analysis very straightforward. Sensitivity analysis was performed to understand the relationship between cost, the number of patients at the time of the earthquake, and the length of the outage. The number of patients and the length of the water outage are important factors in driving the cost. Most costs are per day, per patient, or per patient day and, as such, uncertainty in these factors can greatly influence the expected cost. These parameters are also interesting because they are truly unknown. Management will not know how many patients will be present until the time of the event. Even after the event occurs, some time will pass before they know how long the outage will last.

As expected, the water outage duration directly impacts costs. Figure 4.14 represents cost versus outage length for 200 trials using varied input parameters as described previously. The length of the water outage increases costs fairly linearly. The diamonds on the graph represent trials in which evacuating the hospital was recommended. Longer outage durations are associated with evacuation being the optimal solution.

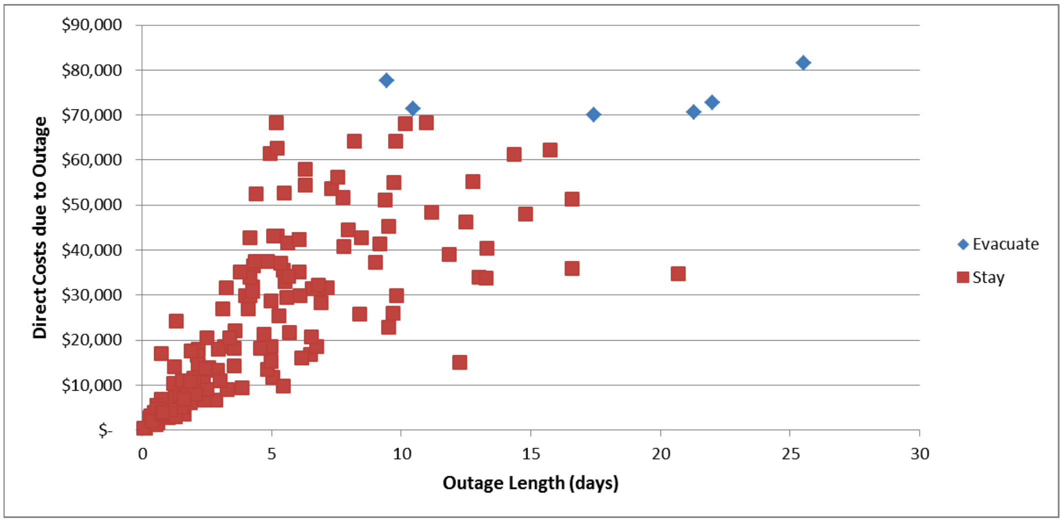

Figure 4.14: Costs and Length of Water Outage

Unlike outage length, patient population did not have a strong effect on total direct costs due to water outage. This is partially because costs such as sterilization, sanitary facilities and HVAC water use will be fairly constant despite shifts in patient population. Additionally, variation in patient population isn't strong enough to drive any large changes by itself. Figure 4.15 shows direct costs relative to the patient population.

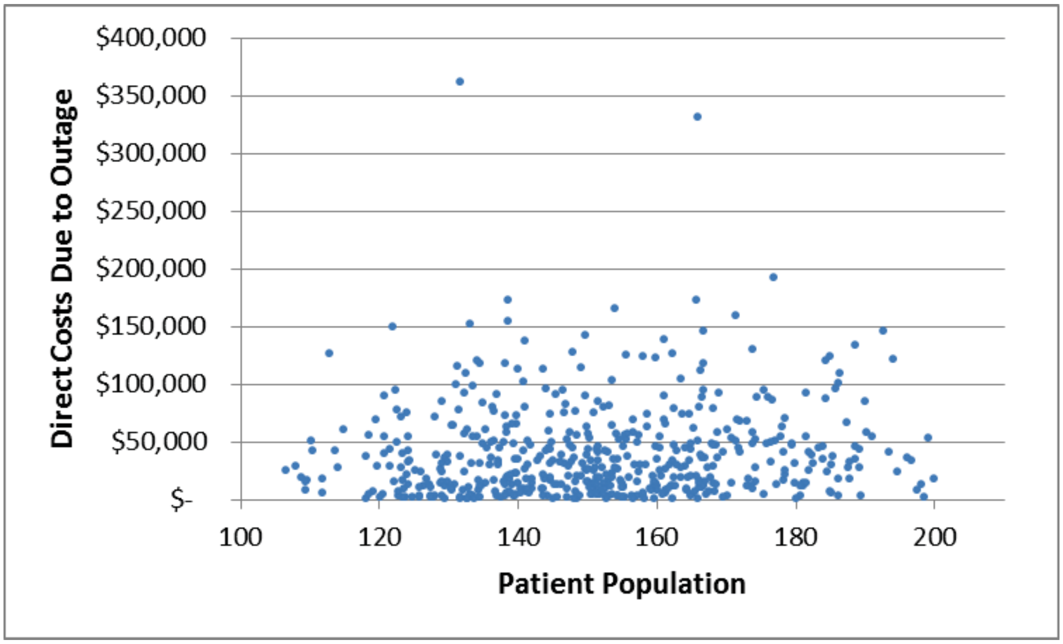

Figure 4.15: Costs and Patient Population

4.6.7 Review of Model and Analysis

This section describes the strengths and weakness of the analysis along with critical assumptions and omissions.

4.6.7.1 Strengths of the Analysis

The optimization model plays two important roles in helping the stakeholders to make better decisions. First, given particular circumstances through which it is possible to know how many patients are actually present in each unit immediately following the outage, these actual data can be incorporated in the optimization model by setting the restrictions of X_1, X_2, Y_1 and Y_2 to be equal to the real number. By doing this, stakeholders will be able to restrict the operational cost so that it is minimized, not only according to whether or not it is cheaper to contract or give in-house food services, but also according to the total amount of water available. The optimization model can be understood to be a representation of a competition, where competitors are all the variables explained above, which take integer and/or binary values so that the total cost is minimized while satisfying all the restrictions as well. In other words, the optimization model evaluates whether it is cheaper to contract food services or not, while also evaluating whether to subcontract sanitary service or not, and simultaneously evaluate if the cheapest action is to transfer patients. Secondly, if a pre-event analysis where to be conducted, the optimization model could be run several times while changing both the number of patients to be transferred and the amount of water available each day during the outage. This way a less deterministic approach would allow the decision makers to understand how decisions on evacuation could change by switching from a contracting services approach to an in-house approach.

Another strength of the model is its ability to simulate different input values. This allows it to evaluate a given decision or perform optimization using sampled input parameters. This is useful for examining a range of inputs.

4.6.7.2 Weaknesses of Analysis

There are a number of weaknesses in the analysis. Data quality, changes over time, and the inclusion of mortality and morbidity impacts are all areas where the model could be improved.

4.6.7.2.1 Data Quality

There is a considerable amount of uncertainty about the input parameters. While we have tried to make them as reasonable as possible, their actual values may vary. The model takes into account variability for many inputs by considering distributions, but in most cases a uniform distribution was assumed because we were only able to approximate the bounds of each parameter. Since the distributions do not reflect their actual distribution for each parameter, the financial risk histograms are of questionable accuracy. Better information about the values and distribution of each would make them more representative of the actual financial risk involved with each decision.

Additionally, only direct costs are included in the model. As a result, the financial risk reflected in the output is incomplete and very low. The model does not account for costs associated with loss of revenue, loss of reputation (i.e., opportunity costs), administration, patient transfer (beyond the ambulance costs), and reopening of the hospital.

4.6.7.2.2 Changes Over Time

The model does not take into account the dynamic nature of decisions and consequences. The model assumes that in the first hours after the earthquake, hospital management will make all of the decisions and then stick to those decisions for the duration of the outage. However, conditions will change and decisions will continue to be made throughout the duration of the event. Another limitation is the assumption that patients will only be discharged on the day of the outage and the patient population will remain static until the end of the outage. The model also assumes that although costs may vary for each run that for any given water outage, the costs, water availability and water use will remain constant throughout the duration of the outage.

4.6.7.2.3 Morbidity and Mortality

Concerns for patient health are frequently cited as a significant issue when hospitals and long term care facility staff discuss evacuation versus shelter-in-place

(Bagaria et al, 2009; Hyer, Polivka-West & Brown, 2007). However, the model does not address patient health or safety when considering evacuation. This is partly due to a lack of clear evidence. Researchers have only recently started studying the effects of evacuation on the health of institutionalized populations.

Dosa et al. (2012) studied the effects of hurricane evacuation on nursing home residents to determine if evacuations are associated with an increase in mortality and morbidity. The researchers gathered data about Louisiana nursing homes and residents from multiple sources available through the Centers for Medicare and Medicaid Services. They studied residents who were in nursing homes that evacuated for Hurricanes Katrina, Rita, Gustav, or Ike. By comparing mortality and morbidity in the preceding years against rates in the year of the named storms, the authors noted an increase in deaths and hospitalizations 30 days and 90 days after evacuating for the hurricanes.

To determine the increase in deaths and hospitalizations, the researchers calculated the average rates for the two years preceding the hurricanes and projected it on the storm year. Then, the difference (increase in all cases) between the projected and actual deaths and hospitalizations was attributed to the evacuations. Because the researchers only looked at a three year period in each case, it does not appear the methodology adequately accounted for natural variability. This is particularly troubling since the difference in mortality and morbidity is the result of an average taken from only two years.

At present, this research appears to be unique in its attempt to quantify the increased risk to nursing home resident health from evacuation. I was unable to find similar research studying the effects on hospital inpatients. The CMS does, however, track 30-day mortality for hospitalized patients 65 years of age and older. For purposes of this model, I may use the figures for the Memphis VAMC as the base rate and apply the nursing home resident increase of risk as illustrative of the increased risk hospital patients may face from an evacuation.

Due to the variability in the results and the small sample size, it is difficult to make broad generalizations about the size of the effect evacuation has on nursing home resident morbidity and mortality. However, the results are consistent in showing an increase in mortality and hospitalizations at 30 and 90 days after the evacuations. This supports the anecdotal concerns expressed by health care providers about the negative consequences associated with evacuating frail and unhealthy people.

Research comparing multi-year mortality and morbidity data from hospitals that evacuate for disaster events could provide insights into the comparability of hospital patients and nursing home residents in similar circumstances. Data available through the Centers for Medicare and Medicaid Services can provide 30-day mortality and re-hospitalization rates for hospital patients 65 years of age and older.

Were reliable data available from which to project mortality and morbidity rates associated with a hospital evacuation, the model could provide a more complete view of the costs associated with maintaining health care operations or closing the facility.

4.6.7.3 Critical Assumptions

The analysis is dependent on the variables and the data representing each of the inputs. The variables selected for study are intended to be representative of the most water demanding medical and support services in the hospital. The values assigned for each variable are based on limited research, which was constrained by time and funding.

4.6.7.4 Critical Omissions

Modern hospitals are very complex systems and, due to necessity, we made a number of simplifications. The financial implications of a water outage and the subsequent efforts to continue service or close the hospital have associated costs, many of which we have not considered. We have limited our scope to just two areas of the hospital (the Intensive Care Unit and the Medical-Surgical Wards) in order to capture the inpatient population and have chosen not to examine surgery, radiology, laboratory, or any of the other units at the hospital. This same limitation extends to the hospital support services. We only considered central sterilization, food services, toilet services, and HVAC, which are the primary users of water. We have also limited our analysis to direct costs of the water outage associated with contracting outside support services and procuring bulk water to meet the demands of in-house services. We have not considered costs or benefits associated with needing more or fewer staff or other support services. We also haven't considered the other costs and benefits associated with closing the hospital such as savings in staffing, losses in revenue and other factors. While these have been omitted largely for simplicity, we do believe that these costs are less important in a Veterans Administration hospital, which has mostly fixed income and costs.

This analysis is focused exclusively on costs. It does not evaluate the possible impact of transfers on in-patient morbidity or mortality or other criteria that may assist decision-makers in selecting a course of action. Future analysis should be more robust and include non-monetary criteria that will provide decision makers with a more complete understanding of the possible impacts of their decisions.

4.6.8 Value of the Model

Optimization models can be powerful tools to support decision making. Their ability to evaluate multiple courses of action in light of a range of inputs allows users to consider many scenarios simultaneously. However, the tool is limited by the variables included in the model and the quality of the data used to quantify the variables. When we define variables, we put value on what, and how, we measure those elements we deem important to understanding and/or solving the problem. The choice of variables is reflected in the model’s output and affects the recommended course of action. For example, the model described in this chapter seeks to identify the option with the lowest cost. Other considerations are not prioritized or included.

The nature of quantitative models, with their use of variables, mathematical equations, and (frequently) computers to run calculations, can make them equivalent to a black box for decision makers. For those leaders who do not take the time to learn the inner workings of the model, they may either blindly accept the results or dismiss the recommendations as academic rather than practical. The complexity of the computer dependent model can also mask errors and may produce erroneous results if unseen mistakes affect recommendations.

The use of the model output in decision making is indicative of how essential it is that users understand the model's structure, variables, and data collection methods. Data quality may be the most important among these since the results are driven by the information put into the model (i.e., garbage in, garbage out). For this reason, the act of developing the model is more important to our understanding than the model itself. A popular parallel idea is that planning is more important than the plan.

4.7 Conclusion

To advance our understanding of health facility functionality and the systems necessary to maintain operations, we need to improve our understanding of how to apply mitigation and preparedness activities that increase the likelihood our medical treatment facilities will be available when we need them. We must determine what we expect from our hospitals and their supporting systems during disruptive events and plan accordingly. We must consider the role we want our health care facilities to play in the community following disasters. We must identify the capabilities we expect to be maintained.

Once we have identified the capabilities that require continuity, we can begin planning for their survivability. We need to understand our hospitals and their functionality in terms of the interconnected systems, both internal and external to the facility, that enable providers to deliver health care to patients. Then, we can survey the full range of threats that can negatively affect our hospitals and the systems on which they depend. We must also consider how different characteristics of those threats can affect those systems in different ways. Evaluating the breadth of exposure to these hazards in their various forms will provide planners and decision makers with the information necessary to understand the system-wide vulnerabilities our hospitals face and forecast possible consequences from the range of threats. Protective action in the form of mitigation and preparedness activities should be grounded in that examination. The influence diagram and HVMF are two tools that can be employed to support the analysis.

That analysis should be incorporated into the project parameters of new hospitals and renovations to ensure the design and construction meet the needs of the community during both normal circumstances and disaster occasions. Additionally, the role that flexibility plays in enabling hospitals to meet the needs of their patients and other members of the community during disasters needs to be considered and included in hospital designs and organizational planning. Staffs must be able to adapt their resources to changing demands and coordinate with other organizations to maintain their essential services.

Chapter 5

CONCLUSIONS, FUTURE RESEARCH, AND CONTRIBUTIONS

This chapter describes the observations and recommendations drawn from research. It also identifies opportunities for future research and summarizes the contributions provided by the research.

5.1 Synthesis

This section briefly summarizes the key points and findings described in Chapter 4.

5.1.1 Community Support

Observation 1: During a disaster, hospitals are strategic assets for the communities in which they operate.

When we think about hospital support to communities during disasters, we may focus on health care roles similar to those responsibilities the organizations have day-to-day. We expect their doors to be open to receive patients who need treatment. But hospitals are frequently more than that to their communities. They are also strategic assets with unique capabilities that are necessary in some disaster events, such as decontamination facilities for large hazardous material spills or terrorist attacks involving weapons of mass destruction. Because of their culture of caring for those in need and the relative strength of their facilities, many people consider hospitals to be a safe haven where they can seek shelter and support during a disaster.

5.1.2 Hospital Functionality

Observation 2: Hospital functionality during disruptions is not simply about resources but also flexibility.

Hospital functionality is more than the sum of inpatient beds and staff members per shift. It is the ability of the medical treatment facility to match its resources in meaningful ways to changing health care demands that preserve life and heal the sick. Maintaining that functionality in the face of disruptions and a dynamic environment requires a flexible organization that can innovate, improvise, and apply proven solutions to unique problems. However, it also requires that in extreme circumstances priorities be made that allow resources to be shifted or consolidated in a way that does the most good for the most people.

5.1.3 Influence Diagrams

Observation 3: The functional relationships among the diverse hospital systems can be captured in an influence diagram providing a graphical representation of the possible vulnerable elements and implications of failure.

The influence diagram is a scalable model that enables the visualization of the complex arrangement of systems that bear on a hospital's functionality and, ultimately, its ability to support the community during a disaster event. The diagram is built upon an understanding of the fundamental objective of maintaining a functional hospital and the means objectives necessary to achieve it. The model depicts the internal and external systems, plus the relationships between them, necessary for the delivery of health care. Like a map, the level of detail included in the diagram can be tailored to the user. By depicting functional relationships, the model allows us to see how the hospital's dependent systems are vulnerable to disruption by providing a more comprehensive view of their exposure to threats and the manner in which a disruption can propagate through and between the systems. This understanding also reveals opportunities for applying protection measures in the form of mitigation and preparedness actions.

5.1.4 Hazard Vulnerability Mitigation Framework

Observation 4: The Hazard Vulnerability Mitigation Framework (HVMF) provides context for the hazard and the possible mitigation and preparedness measures.

As a mental model, the HVMF provides a more comprehensive, all-hazards approach to thinking about hazards, their agents and characteristics, exposure, vulnerabilities, consequences, and mitigation and preparedness. The framework supports the consideration of risks faced by hospitals by tying threats, exposure, and vulnerability to consequences, which establishes the basis for identifying protective actions. A hazard vulnerability analysis that does not include consequences or lead to the identification of mitigation and preparedness actions is incomplete.

5.1.5 Optimization Model

Observation 5: Optimization models, with the limitations of the completeness, assumptions, data quality and accuracy of the models, provide insights into the process and complexities.

Quantitative models can be powerful tools for understanding complex problems and supporting decision making. However, at their best, they are still an imperfect representation of reality. The process of creating the model, determining what should be included and excluded, identifying and quantifying the variables, and finding quality data inform the manner in which we understand the problem, courses of action, and viable solutions. The experience of building the model is more important and valuable than the model itself.

5.1.6 Prioritization and Decision Making

Observation 6: Having a comprehensive understanding of risks and identifying protective actions is different from prioritizing those actions and making capital investment decisions. These tools and findings support informed decisions, but they do not recommend courses of action or solutions.

Some believe financial imperatives trump community health needs (Hanfling et al., 2013). Many hospitals claim they are barely getting by financially.

> There is not a hospital in our area that is making any money. You are lucky if there is a hospital in . . . California that is making any money, and I don't know if there is. But if they are making money, they are making it because they got investments that are making up for, you know, their losses in operation.

Brill (2013) suggests that hospitals are in fact overcharging many patients and making healthy profits. The author offers high salaries for hospital executives as evidence of such largesse. Conover (2013) counters that the American Hospital Association estimates hospitals have a profit margin of 5.5 percent, which is more typical when compared to other industries.

Others suggest that those making executive decisions are frequently far removed from the implications of those decisions (Hanfling et al., 2013). If true, the financial pressures on hospital leaders may have greater resonance than other pressures. If a hospital cannot make money, it cannot stay open. That puts an emphasis on funding day-to-day operations over funding capital improvements or future operations that do not directly improve the bottom line (i.e., mitigation measures).

The tools described in this dissertation do not tell health care executives what protective actions they must take or what capital investments they must make. Rather they are intended to help hospital owners and their staffs better understand the risks they face and make more informed decisions about disaster planning and preparations.

5.2 Policy Implications

This section identifies recommendations to improve the survivability of hospitals and their nonstructural systems through planning and design.

5.2.1 Planning for Community Support during Disaster Events

Recommendation 1: Incorporate the role the hospital will have in community disaster response during planning and design.

Recognizing that hospitals are community strategic assets, it is important to determine how we want them to function during both normal and disaster situations. Department of Defense criteria specify that when planning a new hospital, the installation (community) determines if the facility is mission essential, which means it is necessary during an emergency or disaster event. If deemed essential, the community and hospital identify those functions that must be available under all circumstances and their capacities. Underlying the decisions about health care capabilities during disruptions is the functionality of the systems on which hospital services depend. Identifying these dependencies and incorporating the survival of these systems into the hospital's physical and organizational structures is an important element of planning and design.

The influence diagram is a tool that can help planners, designers, and organizational leaders identify the functional relationships that exist within hospitals and beyond to support health care operations. The HVMF provides a framework from which to ground mitigation and preparedness actions in a comprehensive analysis of hazards, exposures, vulnerabilities, and consequences.

5.2.2 Planning and Designing for Flexibility

Recommendation 2: Maximize support of operational flexibility in facility planning and design.

As problem solving organizations, hospital staffs combine the resources available to them in proven or novel ways to meet the demand of their patients and the community. They do this every day. During disaster events, health care demands put an added strain on limited resources. The hospital's success depends on the ability of its personnel to marshal staff, structure, and stuff effectively. It requires flexibility, innovation, and improvisation.

As a resource, the building and its nonstructural systems can support this flexibility. Planners and designers can anticipate increases in demand and alternate uses of spaces. They can consider how additional patients, staff, equipment, and supplies might be added to treatment areas. They can anticipate how individuals and families seeking shelter could be accommodated. They can include those increased loads into their building utility calculations when designing alternate and back-up systems. Architects and engineers are taught to plan for changes in building use over time and to create flexible designs that are accommodating. Such designed flexibility should be applied to planning for disasters.

5.2.3 Protective Action and Code Compliance

Recommendation 3: Apply a holistic approach to understanding risk that entails a comprehensive analysis of threats, exposure, vulnerabilities, and consequences so that mitigation and preparedness actions are grounded in the specific circumstances of a facility or organization. Code compliance is the baseline, not the end state.

Equating code compliance with safety and reliability may be indicative of an incomplete understanding of risk. When asked about measures their hospital had taken to lessen damage and loss of function during a disaster event, one respondent from the hospital mitigation project said,

> We upgraded all of our boilers and our chill rooms recently, so we're pretty much guaranteed heat and air conditioning throughout the years, so from an environmental perspective, we're okay.

It is not clear if the respondent understands the complexity of the hospital's HVAC system or the reliance on external systems for its functioning. However, his statement seems overly optimistic. Similar concerns can apply to any system in the hospital.

Using code compliance as a proxy for safety, one of the expert panelists spoke about the unsoundness of a hospital's structural integrity following an earthquake. However, he suggested that if the building is "up to code" there is less concern about its structural integrity.

> I think what was interesting was the unsureness of the integrity of the structures. And I think that the more you have planning, and it's up to code, the more sure they seem to be getting out the full functionality.

There may be a corollary between this type of faith in code compliance and component-centric mitigation that overemphasizes protecting high visibility elements without increasing the safety of the overall system. For example, when the emergency generators at New York's Bellevue Hospital were installed on the facility's 13th floor, the back-up electrical system was still at risk from flooding because the fuel pumps remained in the basement.

To be most effective, protective action should be grounded in a comprehensive analysis of hazards, exposure, vulnerabilities, and the consequences of disruptive events. The many facets of threats and the myriad ways they can impact a hospital and its operations must be understood. This requires both a broad understanding of the hazards, but also a comprehensive appreciation of the internal and external systems upon which the hospital relies. This knowledge enables the organization to forecast ways in which health care delivery may be disrupted and the possible consequences of such events. From that knowledge, the health care leadership can identify and prioritize the protective actions they need to take without losing sight of their residual risk. The influence diagram and HVMF are tools that support this approach.

5.3 Future Research

This project provides the basis for much additional research. These efforts can be broadly categorized as putting the tools into practice, priorities and decision making, and challenging underlying assumptions.

5.3.1 Putting the Tools into Practice

The influence diagram, HVMF, and optimization model are only three possible tools that may inform a greater understanding of hospital survivability following major disruptions. Their integration into the medical treatment facility planning and design processes and hospital disaster planning activities requires additional effort. Putting the tools into practice will require their incorporation into existing practices and ensuring their employment adds value commensurate with any additional effort.

The military's Capital Investment Proposal, which includes planning assumptions and a brief project narrative, should state explicitly what the installation (community) expects of the hospital during a disaster. Beyond merely justifying whether the facility is mission essential, the planners should identify how the hospital is expected to perform during a disruption. Such a narrative might be included as part of the project description, or it could be a separate statement provided for all hospital projects. Perhaps installations (military communities) should have to justify why hospitals are not mission essential rather than proving they are so. Tertiary and quaternary hospitals, in particular, have unique capabilities that may not exist elsewhere in a community. Assuming mission essentialness would default to more emphasis on continuity of operations, not less.

Because the influence diagram and HVMF were developed to inform the hospital planning and design processes, they should be incorporated into the early stages of the planning process. The influence diagram may first be populated during the planning charrette. Then, it would be continually updated and refined through the planning, design, and construction processes so that it can be provided to the hospital end users at project completion. The hospital staff could then use the influence diagram to inform its HVA and disaster planning.

Similarly, the HVMF can also be introduced during the planning charrette to increase the comprehensiveness of the threat analysis and, in conjunction with the influence diagram, lay the groundwork for protective actions to be based on the hazards, vulnerabilities, and possible consequences faced by that particular facility.

Like the influence diagram, the analysis supported by the framework could be continuously updated and refined through planning, design, and construction. Then, the analysis could form the basis for the HVA performed by the hospital, upon which their disaster plans are built, and to meet The Joint Commission accreditation requirements.

Both the expert panel and participants in the American Meteorological Society's Building Resilience to Weather for Healthcare Facilities & Services Workshop expressed a need for a holistic view of hospital systems and the systems on which they depend. The influence diagram is a step in that direction. Because the influence diagram is scalable and modifiable, the components within the systems can be depicted in greater levels of specificity. Similarly, the measures of effectiveness for the means objectives can be more specific and may be identified at the component level. It is possible that associating the diagram with a Building Information Model (BIM) may provide greater granularity of the nonstructural components.

The influence diagram could also be modified to include additional elements. Currently, it emphasizes functional elements and relationships. Regulatory, administrative, and organizational factors could be added to recognize the socio-technical context in which hospitals exist and operate. Additionally, the community services block might be expanded to include more organizations. Businesses, governmental organizations, not-for-profits, and volunteer organizations that directly or indirectly affect hospital operations could be added.

Operationalizing the HVMF will require some adjustments, too. The expert panelists agreed that putting the framework into practice is going to require effort toward making it user friendly. If it is going to be adopted, it cannot be more onerous than the existing risk analysis tools. Some respondents suggested a menu based, electronic tool that speeds up the process of identifying hazards, exposures, vulnerabilities, and consequences would give users more time to consider mitigation and disaster preparedness actions.

Beyond preparing the models for practice, we also need to determine how best to communicate the tools to the hospital emergency management and design communities. People must be made aware of their existence and how they can be incorporated into disaster planning and hospital planning and design.

5.3.2 Priorities and Decision Making

The influence diagram and HVMF are structured to support a comprehensive understanding of hospitals and their dependent systems and the risks and implications of a service disruption. In their current form, neither model identifies system priorities or puts values of relative importance on threats, vulnerabilities, consequences, or protective measures. They support increased knowledge and a common operating picture for stakeholders with varying interests and points of view.

The influence diagram does not address the importance of systems and relationships relative to the delivery of health care. If we prioritize mission essential functions, we should also prioritize the systems on which they depend. Perhaps the importance of nonstructural systems can be measured in terms of the number of functions that rely on them for their proper operation. Together, the influence diagram and HVMF may help identify opportunities for protective action based on desired capabilities during disaster events.

Financial imperatives are not in the forefront of the influence diagram and HVMF presented in this dissertation. The availability of money to pay for mitigation, preparedness, and recovery is clearly a factor in implementing protective measures. In addition, insurance is a form of mitigation that protects organizations from financial losses. It aids in recovery through reimbursement for losses and liability. Research into the role money plays in problem analysis and decision making in a hospital emergency management context could aid planners in determining how best to support health care and community leaders toward greater survivability of hospital systems.

5.3.3 Challenging Underlying Assumptions

Business operations and sustainability tend to emphasize efficiency in an attempt to gain the maximum benefit from limited resources. An unintended consequence may be increased risk from disruptions as negative impacts reverberate through tightly coupled systems. The balance between effectiveness and efficiency, particularly in the context of mitigation and preparedness actions, is ripe for study.

The influence diagram is facility-centric. It represents the systems associated with a particular hospital. Given the formal and informal support relationships that exist among health care organizations, there may be benefit to creating a multiple hospital model that represents influences at a community level.

There is an underlying assumption that increased survivability of hospital systems and continuity of health care will have a positive impact on patients. While research indicates evacuations have negative effects on nursing home residents, the City of New York proudly proclaimed that no patients died as a result of the hospital evacuations after Hurricane Sandy. Determining the impact of evacuations on hospitalized patients would provide insight into the effects of health care service loss or disruption and could influence how protective actions are considered during facility planning and design.

5.4 Contributions

This research offers several unique contributions, including a comprehensive literature review, an overview of the context in which hospitals prepare for disruptions, and a set of tools to improve our understanding of the complex nature of maintaining health care delivery. No one has systematically studied the problem in this way before.

The research developed and applied lessons from disaster science and hospital emergency management to medical facility planning and design for the purpose of improving the survivability of nonstructural systems to increase the likelihood that medical treatment facilities remain operational following disasters. The research developed a set of tools that inform a policy recommendation to the U.S. Army that may influence the manner in which the Service approaches the planning of military medical facilities.

This project developed a comprehensive review of the literature addressing hospital functionality in a disaster context with an emphasis on nonstructural systems. It combined previous research from multiple domains such as the hospital emergency management literature, which focuses on operational aspects of health care operations, like medical surge, triage, and hospital evacuations, and engineering literature that studies factors of resilience in hospital systems and critical infrastructure. This project brings knowledge from different fields, with well-defined processes, to the complex problem of enabling hospitals to survive disruptions. The literature review also highlighted the challenges in addressing hospital functionality quantitatively. Data are sparse and quality is questionable.

The overview of the context in which hospitals prepare for disaster events addresses national policy and strategic goals for health care emergency management, challenges that affect the continuity of hospital operations, and the role nonstructural systems play in the delivery of health care. It also describes the process the U.S. military takes to plan and design its medical treatment facilities and how that affects operational capabilities.

The project developed a set of tools that improve the manner in which we consider the continuity of hospital operations and hospital survivability to disruptions. The influence diagram is the first graphical depiction of the functional relationships between internal and external systems and components necessary for the delivery of health care. It advances us toward the goal of understanding more completely the full range of systems upon which our hospitals rely and knowing those systems completely. The HVMF combines concepts from the natural, applied, and social sciences to depict the relationships between hazards, exposure, vulnerability, consequences, and protective action. The framework supports a more complex understanding of risk in the context of hospital functionality. The illustrative optimization model provides an example of the quantification of risk associated with a loss of service on health care operations.

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Appendix A

ACRONYMS

A/E	Architect/Engineer
BIM	Building Information Model
CIDM	Capital Investment Decision Model
CIKR	Critical Infrastructure and Key Resources
DMORT	Disaster Mortuary Operational Response Team
DRC	Disaster Research Center
EMS	Emergency Medical Services
EOC	Emergency Operations Center
ESF	Emergency Support Function
HAvBED	Hospital Available Beds for Emergencies and Disasters
HICS	Hospital Incident Command System
HVA	Hazard Vulnerability Analysis
HVAC	Heating, Ventilation, and Air Conditioning
HVMF	Hazard Vulnerability Mitigation Framework
IBC	International Building Code
IRB	Institutional Review Board
MCEER	Multi-Disciplinary Center for Earthquake Engineering Research
METL	Mission Essential Task List
MHS	Military Health System
MMI	Modified Mercalli Intensity

NFPA	National Fire Protection Association
NHSS	National Health Security Strategy
NIMS	National Incident Management System
NRF	National Response Framework
NYU	New York University
PAHO	Pan American Health Organization
PAHPA	Pandemic and All-Hazards Preparedness Act
TJC	The Joint Commission
UFC	Unified Facilities Criteria
UTMB	University of Texas Medical Branch
VOIP	Voice Over Internet Protocol

Appendix B

GLOSSARY

Care, Quaternary. Quaternary care is more specialized that tertiary care and may not be available in all hospitals. It consists of very specialized and uncommon procedures and treatments.

Care, Primary. Health care on an outpatient basis that is primary care provider who may be a physician, physician's assistant, or nurse practitioner. A primary care provider may refer patients to a secondary care facility for more specialized care.

Care, Secondary. Secondary care is usually provided by referral from a primary care provider. Secondary care can occur in a hospital and may include inpatient, surgical, and more specialized health care services.

Care, Tertiary. Tertiary care is provided by referral from a primary or secondary care provider. It is provided by specialized health care personnel. This level of care is typical in many hospitals in the U.S.

Defend in Place. This concept is specific to fires. It is similar to shelter-in-place in that individuals do not evacuate the facility but rather utilize areas of refuge, smoke barriers, and fire barriers to separate themselves from immediate danger. This approach assumes an active fire response will contain or extinguish the fire and rescue the building occupants.

Disaster, Natural. Disaster events precipitated by a natural process, such as hurricanes, earthquakes, and floods.

Disaster, Human Induced. Disaster events precipitated by a human process that is typically purposeful rather than accidental. Examples include labor disputes, mass gatherings, and acts of terrorism.

Disaster, Technological. Disaster events precipitated by a technological process that is frequently accidental, including transportation and hazardous material accidents.

Evacuation, Complete. The removal of all people from a building to protect them from danger.

Evacuation, Horizontal. The movement of people within the floor of a building to protect them from danger. This is commonly employed in fire response where people move to the opposite side of a smoke or fire barrier to escape immediate danger.

Evacuation, Partial. The removal of all people from the portion of a building, such as a wing, tower, or floor, to protect them from danger.

Evacuation, Vertical. The movement of people from one floor to another to protect them from danger. The movement can be either up or down depending on the character of the threat.

Healthcare Capacity. A measure, or series of measures, intended to describe the number of patients for which a hospital can provide care.

Hospital Incident Command System (HICS). A model for organizing a hospital's response to a disaster based on a flexible, scalable, and functionally aligned hierarchical framework. The organizational structure consists of an incident commander above four functional section chiefs who represent planning, operations, logistics, and finance/administration. The responsibilities for each of the positions are detailed in job action sheets.

Shelter in Place. A defensive action taken to protect people from a hazard wherein they stay in a given building or location that is determined safe enough to protect and support them during the impact period of a disaster.

Surge Capacity. A measure, or series of measures, intended to describe the ability of a hospital to accommodate a sudden increase in the number of patients presenting at the hospital.

Threat, External. These are threats that originate outside of the facility. Natural hazards, such as hurricanes and tornados, are an example.

Threat, Internal. These are threats that originate inside the facility. Internal chemical spills and internal fires are examples.

Throughput. A measure of the number of patients can be treated at a hospital within a given timeframe.

Appendix C

NATIONAL HEALTH SECURITY STRATEGY

The National Health Security Strategy consists of two goals, ten strategic objectives, eight essential capabilities, and 50 sub-capabilities (U.S. Department of Health and Human Services, 2009). Improving the survivability of hospitals and their nonstructural systems supports this national strategy.

Goals:

1. Build community resilience.
2. Strengthen and sustain health and emergency response systems.

Strategic Objectives:

1. Foster informed, empowered individuals and communities
2. Develop and maintain the workforce needed for national health security.
3. Ensure situational awareness.
4. Foster integrated, scalable health care delivery systems.
5. Ensure timely and effective communications.
6. Promote an effective countermeasures enterprise.
7. Ensure prevention or mitigation of environmental and other emerging threats to health.
8. Incorporate post-incident health recovery into planning and response.
9. Work with cross-border and global partners to enhance national, continental, and global health security.
10. Ensure that all systems that support national health security are based upon the best available science, evaluation, and quality improvement methods.

Essential Capabilities:

1. Community Resilience and Recovery.
    a. Public education to inform and prepare individuals and communities.
    b. Public engagement in local decision making.
    c. Local social networks for preparedness and resilience.

d. Integrated support from non-governmental organizations.
e. Emergency public information and warning.
f. Post-incident social network re-engagement.
g. Case management support or individual assistance.
h. Reconstitution of the public health, medical, and behavioral health infrastructure.
i. Mitigated hazards to health and public health facilities and systems.
j. Support services network for long-term recovery.

2. Infrastructure.
   a. Sufficient, culturally competent, and proficient public health, health care, and emergency management workforce.
   b. Volunteer recruitment and management.
   c. Interoperable and resilient communications systems.
   d. Legal protections and authorities.

3. Situational Awareness.
   a. Risk assessment and risk management.
   b. Epidemiological surveillance and investigation.
   c. Animal disease surveillance and investigation.
   d. Agriculture surveillance and food safety.
   e. Chemical, biological, radiological, nuclear, and explosives (CBRNE) detection and mitigation.
   f. Monitoring of available health care resources.
   g. Laboratory testing.
   h. Near-real-time systems for capture and analysis of health security-related data.
   i. Information gathering and recognition of indicators and warning.
   j. Coordination with US and international partners.

4. Incident Management.
   a. On-site incident management and multi-agency coordination.
   b. Communications among responders.
   c. Critical resource monitoring, logistics and distribution.

5. Disease Containment and Mitigation.
   a. Research, development, and procurement of medical countermeasures.
   b. Management and distribution of medical countermeasures.
   c. Administration of medical countermeasures.
   d. Community interventions for disease control.

6. Health Care Services.
   a. Access to health care and social services.
   b. Evidence-based behavioral health prevention and treatment services.

c. Medical equipment and supplies monitoring, management, and distribution.
d. Use of remote medical care technology.
e. Emergency triage and pre-hospital treatment.
f. Patient transport.
g. Medical surge.
h. Palliative care education for stakeholders.
i. Fatality management.
j. Monitoring of physical and behavioral health outcomes.
k. Application of clinical practice guidelines.

7. Population Safety and Health.
   a. Responder safety and health.
   b. Emergency public safety and security.
   c. Individual evacuation and shelter-in-place.
   d. Mass care (sheltering, feeding, and related services).
   e. Environmental health.
   f. Potable water/wastewater and solid waste disposal.

8. Quality Improvement and Accountability.
   a. Use of capability-based performance measures.
   b. Use of quality improvement methods.

Appendix D

PUBLIC HEALTH PREPAREDNESS CAPABILITES: NATIONAL STANDARDS FOR STATE AND LOCAL PLANNING

The Center for Disease Control and Prevention identified 15 public health capabilities in six domains (U.S. Department of Health and Human Services, 2011). Improving the survivability of hospitals and their nonstructural systems supports public health preparedness.

Public Health Preparedness Domains and Capabilities:

1. Biosurveillance.
   a. Public health laboratory testing.
   b. Public health surveillance and epidemiological investigation.

2. Community Resilience.
   a. Community preparedness.
   b. Community recovery.

3. Countermeasures and Mitigation.
   a. Medical countermeasure dispensing.
   b. Medical materiel management and distribution.
   c. Non-pharmaceutical interventions.
   d. Responder safety and health.

4. Incident Management.
   a. Emergency operations coordination.

5. Information Management.
   a. Emergency public information and warning.
   b. Information sharing.

6. Surge Management.
   a. Fatality management.
   b. Mass care.

c. Medical surge.
d. Volunteer management.

Appendix E

HEALTHCARE PREPAREDNESS CAPABILITIES: NATIONAL GUIDANCE FOR HEALTHCARE SYSTEM PREPAREDNESS

The Department of Health and Human Services identified eight capabilities and 29 functions regarding healthcare system preparedness (U.S. Department of Health and Human Services, 2012). Improving the survivability of hospitals and their nonstructural systems supports health care system preparedness.

Healthcare System Preparedness Capabilities:

1. Healthcare System Preparedness.
   a. Develop, refine, or sustain Healthcare Coalitions.
   b. Coordinate healthcare planning to prepare the healthcare system for a disaster.
   c. Identify and prioritize essential healthcare assets and services.
   d. Determine gaps in the healthcare preparedness and identify resources for mitigation of these gaps.
   e. Coordinate training to assist healthcare responders to develop the necessary skills in order to respond.
   f. Improve healthcare response capabilities through coordinated exercise and evaluation.
   g. Coordinate with planning for at-risk individuals and those with special medical needs.

2. Healthcare System Recovery.
   a. Develop recovery processes for the healthcare delivery system.
   b. Assist healthcare organizations to implement Continuity of Operations (COOP).

3. Emergency Operations Coordination.
   a. Healthcare organization multi-agency representation and coordination with emergency operations.
   b. Assess and notify stakeholders of healthcare delivery status.
   c. Support healthcare response efforts through coordination of resources.
   d. Demobilize and evaluate healthcare operations.

4. Fatality Management.
    a. Coordinate surges of deaths and human remains at healthcare organizations with community fatality management operations.
    b. Coordinate surges of concerned citizens with community agencies responsible for family assistance.
    c. Mental/behavioral support at the healthcare organization level.

5. Information Sharing.
    a. Provide healthcare situational awareness that contributes to the incident common operating picture.
    b. Develop, refine, and sustain redundant, interoperable communication systems.

6. Medical Surge.
    a. The Healthcare Coalition assists with the coordination of the healthcare organization response during incidents that require medical surge.
    b. Coordinate integrated healthcare surge operations with pre-hospital Emergency Medical Services (EMS) operations.
    c. Assist healthcare organizations with surge capacity and capability.
    d. Develop Crisis Standards of Care guidance.
    e. Provide assistance to healthcare organizations regarding evacuation and shelter-in-place operations.

7. Responder Safety and Health.
    a. Assist healthcare organizations with additional pharmaceutical protection for healthcare workers.
    b. Provide assistance to healthcare organizations with access to additional Personal Protective Equipment (PPE) for healthcare workers during response.

8. Volunteer Management.
    a. Participate with volunteer planning processes to determine the need for volunteers in healthcare organizations.
    b. Volunteer notification for healthcare response needs.
    c. Organization and assignment of volunteers.
    d. Coordinate the demobilization of volunteers.

Appendix F

INSTITUTIONAL REVIEW BOARD APPROVAL LETTERS

UNIVERSITY OF DELAWARE

RESEARCH OFFICE

210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

DATE:	April 23, 2013
TO:	James Goetschius
FROM:	University of Delaware IRB
STUDY TITLE:	[458430-1] Improving Hospital Survivability: Tools to Inform Hospital Planning and Design
SUBMISSION TYPE:	New Project
ACTION:	APPROVED
APPROVAL DATE:	April 23, 2013
EXPIRATION DATE:	April 22, 2014
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # 7

Thank you for your submission of New Project materials for this research study. The University of Delaware IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the study and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the study via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All sponsor reporting requirements should also be followed.

Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.

Please note that all research records must be retained for a minimum of three years.

Based on the risks, this project requires Continuing Review by this office on an annual basis. Please use the appropriate renewal forms for this procedure.

Figure F.1: Original IRB Approval Letter

UNIVERSITY OF DELAWARE

RESEARCH OFFICE

210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

DATE:	September 10, 2013
TO:	James Goetschius
FROM:	University of Delaware IRB
STUDY TITLE:	[458430-2] Improving Hospital Survivability: Tools to Inform Hospital Planning and Design
SUBMISSION TYPE:	Amendment/Modification
ACTION:	APPROVED
APPROVAL DATE:	September 10, 2013
EXPIRATION DATE:	April 22, 2014
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # 7

Thank you for your submission of Amendment/Modification materials for this research study. The University of Delaware IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the study and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the study via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All sponsor reporting requirements should also be followed.

Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.

Please note that all research records must be retained for a minimum of three years.

Based on the risks, this project requires Continuing Review by this office on an annual basis. Please use the appropriate renewal forms for this procedure.

Figure F.2: Amendment IRB Approval Letter

Appendix G

EXPERT PANEL RECRUITMENT LETTER

Date

Expert Panelist's Name
Address
City, State, Zip Code

Dear Expert Panelist's Name:

I am an active duty Medical Service Corps officer and doctoral candidate in the interdisciplinary Disaster Science and Management program at the University of Delaware. I am seeking your participation as a member of an expert panel evaluating the completeness and usefulness of an influence diagram depicting the elements that bear on hospital functionality and a hazard vulnerability analysis framework that represents a manner of understanding hazards, exposures, vulnerabilities, consequences, mitigation, and preparedness in a hospital context.

The panel will consist of a short presentation of each of the models followed by a series of questions posed to the panel. Each member is encouraged to respond to the questions based on their own expertise and point of view. Consensus is not necessary, but I expect the dialogue to add richness to the data.

The model and framework are part of a larger research project that seeks to understand how the survivability of nonstructural systems in medical treatment facilities affects capital investment decisions. The results of this work will inform the development of a policy recommendation intended to improve the planning and design of U.S. military medical treatment facilities.

I anticipate the expert panel will take up to four hours. I am coordinating to hold the meeting at the Defense Health Headquarters. Your participation in this research is completely voluntary, and you can choose to cease your participation at any time without fear of retribution or negative consequences.

Two enclosures with this letter describe the influence diagram and the hazard vulnerability analysis framework.

Thank you for your consideration. Questions regarding the research project and the expert panels can be directed to the undersigned at [phone number] or [email address].

Sincerely,

James B. Goetschius, AICP
Lieutenant Colonel, U.S. Army

Appendix H

INFLUENCE DIAGRAM HANDOUT FOR EXPERT PANEL

Hospitals are systems of systems. The mechanisms and interactions necessary for their operation are geographically dispersed and exceptionally complex. Because of their interconnections it is important to grasp that complexity in order to understand the vulnerabilities hospitals face from the myriad hazards to which they and their support systems are exposed.

To represent the elements and the influences that affect a hospital's functionality, we will develop influence diagrams, which are a graphical depiction of relationships. These diagrams will aid in our understanding of the range of interactions that occur both inside and outside of the facility. Figure 1 depicts high-level relationships between internal and external systems that bear on a hospital's ability to maintain health care operations. Those operations are necessary for the hospital to serve as a community resource during routine and disaster events.

The internal systems consist of hospital services (treatment, ancillary, support, and administrative), staff members, structural systems, nonstructural systems (architectural elements, building utility systems, and building contents), and functional systems (hospital logistics and hospital transportation assets). The external systems include lifelines (i.e., electricity, water, etc.), supply chain, and transportation networks. The external systems extend all the way to raw materials for manufacturing, power generation for electrical systems, and water sources for water lifelines.

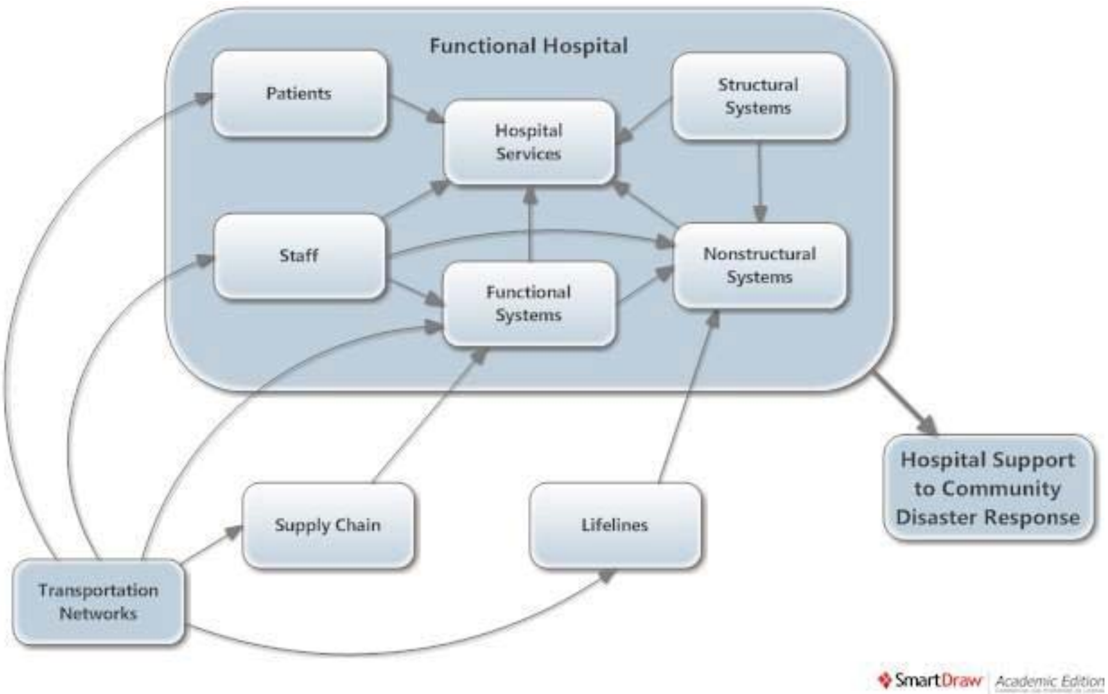

Figure H.1: Influence Diagram

While Figure H.1 provides a broad view of the systems that enable a hospital to remain functional, those systems consist of subsystems with many components and subcomponents. These subsystems, while concentrated geographically, are still very complex. Figure H.2 is an influence diagram depicting a more micro view of hospital system relationships. The water lifeline and hospital water system portion of the figure is essentially a line diagram identifying the major components between the water source and the point of provision. The hospital support services are those water dependent services that enable the provision of health care. Finally, the treatment, ancillary, and administrative services are those caring for patients, performing diagnostics, and handling administrative duties.

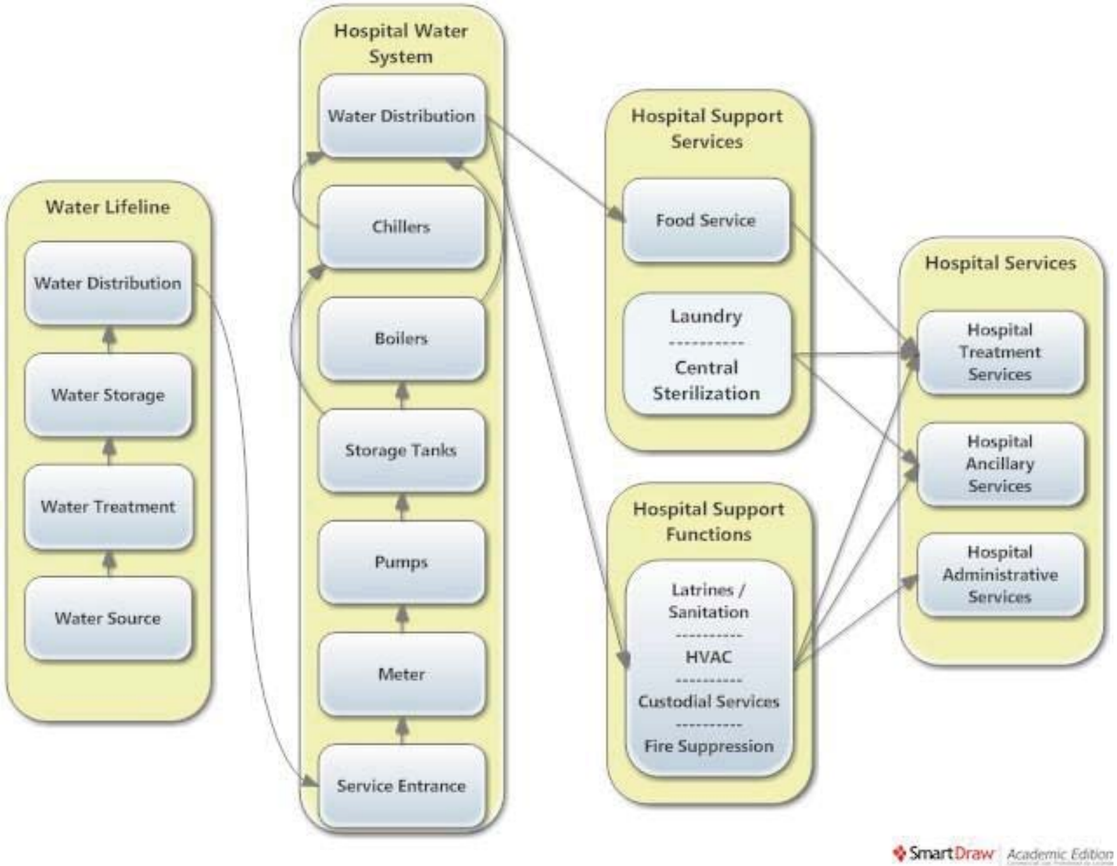

Figure H.2: Influence Diagram

Relationally, Figure H.2 is a partial subset of Figure H.1. A complete influence diagram showing the full breadth and depth of elements and influences both internal and external to the hospital would be exceptionally large and difficult to decipher. Similar attempts to depict large, complex influence diagrams have resulted in figures described as “spaghetti.” By showing the influence diagrams at different scales, we are attempting to create a map-like view that is coherent with different amounts of information at different scales. The closer we get to a particular set of arrangements, the more components, sub-components, and sub-interactions we can see.

Appendix I

HVMF HANDOUT FOR EXPERT PANEL

It is widely recognized that hospital emergency management plans should be grounded in a risk analysis that includes assessing the hazards that threaten and the vulnerabilities inherent in the organization. The Joint Commission first required accredited hospitals conduct annual hazard vulnerability analyses (HVA) in 2001. The Kaiser Permanente HVA Tool has been widely adopted and modified by U.S. hospitals and long term care facilities, including the U.S. Army Public Health Command (PHC), which developed a similar tool for U.S. Army Medical Command requirements.

The Kaiser Permanente HVA and PHC HVA identify all the hazards a medical facility may face, which are divided into four categories: natural, technological, human-induced, and hazardous materials. These categories include both internal and external threats. The hazards are characterized in terms of probability and severity (magnitude – mitigation) to determine the residual risk associated with each hazard. At the end, the hazards are rolled into a summary to compare the risk associated with each category and the probability and severity of any disaster.

The Kaiser Permanente HVA and PHC HVA characterize exposure and vulnerability in terms of preparedness and response capabilities. However, the HVA's lack specificity in the areas of severity, preparedness, and response, which may mask some vulnerabilities or provide an incomplete picture of the risks faced by the hospitals completing the analysis. While the comparison of categories of hazards or probability and severity are interesting, they do little for staff members who are trying to mitigate and prepare for disruptions to their hospitals. For facility-level planning, specificity is important. Understanding that the threats to the individual components of a system may have disproportionate impacts on that system and other systems is necessary. Detailed knowledge of the system components and their dependencies and interdependencies with other components and systems is necessary to gain a more complete understanding of the hospital's exposure and vulnerabilities.

The Joint Commission's standard is vague with regard to what constitutes a HVA. Improvements to the existing tools include clearer definitions of terms and measures, inclusion of essential elements for the provision of health care, the exposure of those essential elements to threats, and the identification of risk reduction measures to further reduce residual risk. Figure I.1 depicts a Hazard Vulnerability Analysis framework that supports a more detailed understanding of hazards and vulnerabilities with added emphasis on the consequences of disruptive events and actions for mitigating their effects. The framework is divided into six major categories: hazards, agents and characteristics, exposure, vulnerabilities, consequences, and mitigation and preparedness. Some of these categories relate directly to one another, but they all build an improved understanding of the hazards that threaten our hospitals, the ways in which we are vulnerable to those hazards, the potential impacts of disastrous events, and actions we can take to avoid or lessen those impacts.

Figure I.1: Hazard Vulnerability Analysis Framework

Table I.1 identifies the definitions for the six categories and their elements.

Table I.1: Definitions for Hazard Vulnerability Analysis Framework

Hazards	Hazards are those events that threaten lives, property, the environment, or organizational operations. They are commonly categorized as natural, technological, or human induced
	Natural. Naturally derived events that threaten lives, property, the environment, or operations.
	Technological. Technologically derived events that threaten lives, property, the environment, or operations.
	Human Induced. Man-made events that threaten lives, property, the environment, or operations.
Agents and Characteristics	Agents and characteristics are those aspects of a hazard that affect its impact on a community, organization, household, or individual. Even for the same type of hazard, differences in characteristics can result in differences in impacts.
	Agent. The element specifically responsible for causing a disruption. For example, the agent responsible for causing flood damage is water.
	Speed of Onset. A measure of the time between awareness of a specific hazardous event and its impact.
	Scope of Impact. A measure of the scale of a hazardous event. It may be measured in terms of geography or the range and depth of activities affected.
	Duration of Impact. A measure of the time that the hazard causes disruption. The length of time necessary to recover from the disruption is an element of this measure.
	Frequency of Impact. A measure of the regularity of a hazard's disruptive events.
	Length of Warning / Existence of Environmental Cues. A measure of the time that individuals are forewarned about a disruptive event. Environmental cues serve as an indicator.

Table I.1 continued

Exposure	Exposure is the possibility that a particular system, component, element, or interaction will be affected by a hazard.
	Systems. An assemblage of interacting, interrelated, or interdependent components or elements working together to form a unified whole. For example, building utility systems in a hospital are composed of many components that are connected to one another and must work together to deliver a given service.
	Components and Elements. The subordinate parts of a system necessary for its functioning. For example, boilers and chillers are components of an HVAC system. However, each of these components is also made up sub-components necessary for their operation.
	Interactions. The connections or influence systems, components, elements, or other units of analysis have on each other.
	Dependencies. To be partially or entirely reliant upon another for some good or service. Systems and their components are frequently dependent on other systems and components for their function. These relationships create coupling such that a disruption in one system can cause a disruption in another system. This can result in cascading failures.
Vulnerabilities	Vulnerabilities are the predisposition of systems, components, elements, or other units of analysis to be negatively impacted by a disruptive event. In hospitals, they are commonly categorized as external or internal.
	External. The predisposition of systems, elements, or other units of analysis outside the hospital to be negatively impacted by an event.
	Internal. The predisposition of systems, elements, or other units of analysis inside the hospital or a part of the hospital to be negatively impacted by an event.
Consequences	Consequences are the resulting impacts of hazards on people, property, the environment, and operations. These are sometimes referred to as “costs” of hazards.
	Fatalities. Loss of life (mortality).
	Injuries. Harm to an individual (morbidity).
	Mental Distress. Mental damage or suffering.
	Service Loss. The loss, disruption, or degradation of elements, systems, or other units of analysis.
	Financial Loss. The loss of money associated with a disaster or disruption and the following recovery.
	Property Loss. The physical loss of property and material due to disasters or disruptions.
	Cost of Adjustments. Costs in terms of time, effort, and money associated with post-disaster adjustments necessary for recovery, mitigation, and preparedness for future disruptive events.
Mitigation and Preparedness	Mitigation and preparedness strategies and actions are those employed to avoid or reduce negative consequences from disruptive events.
	Robustness. Strength, or the ability of elements, systems, and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function.
	Redundancy. The extent to which elements, systems, or other units of analysis exist that are substitutable, i.e., capable of satisfying functional requirements in the event of disruption, degradation, or loss of functionality.
	Rapidity. The capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption.
	Resourcefulness. The capacity to identify problems, establish priorities, and mobilize resources when conditions exist that threaten to disrupt some element, system, or other unit of analysis; resourcefulness can be further conceptionalized as consisting of the ability to apply material (i.e., monetary, physical, technological, and informational) and human resources to meet established priorities and achieve goals.

Table I.1 continued

	Adaptability. The capacity to learn from disruptions and make structural or behavioral adjustments to reduce or eliminate the impacts of future disruptions.
	Avoidance. The ability to prevent a particular hazard, exposure, or consequence from affecting an element, system, or other unit of analysis.

Appendix J

EXPERT PANEL INFORMED CONSENT

Title of Project: Improving Hospital Survivability: Tools to Inform Hospital Planning and Design

Principal Investigator (s): James Goetschius

Other Investigators: Sue McNeil, James Kendra, and Mia Papas

You are being asked to participate in a research study. This form tells you about the study including its purpose, what you will do if you decide to participate, and any risks and benefits of being in the study. Please read the information below and ask the research team questions about anything we have not made clear before you decide whether to participate. Your participation is voluntary and you can refuse to participate or withdraw at anytime without penalty or loss of benefits to which you are otherwise entitled. If you decide to participate, you will be asked to sign this form and a copy will be given to you to keep for your reference.

WHAT IS THE PURPOSE OF THIS STUDY?

The purpose of this study is to develop and apply lessons from disaster science and hospital emergency management to medical facility planning and design for the purpose of improving the survivability of nonstructural systems to increase the likelihood that medical treatment facilities will remain operational following disasters. The research will draw on expert knowledge from both the military and civilian medical communities. This study is part of a doctoral dissertation. You are being asked to take part in this study because of your unique expertise in hospital operations and administration. Volunteers may be excluded from this study if they lack professional experience working in health care environments. Expert panels will consist of multi-disciplinary groups of 4-6 participants.

WHAT WILL YOU BE ASKED TO DO?

You are being asked to participate in an expert panel that will evaluate an influence diagram based on hospital functionality and a hazard vulnerability analysis framework focused on hospital vulnerability. The panel will be conducted in two parts with a presentation of each model followed by a series of questions presented to the group. Each presentation and question period is expected to last no more than two hours.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

Participating in this study will expose you to minimal risks consistent with those faced in daily life. While confidentiality is not guaranteed, personally identifiable information will not be reported in the analysis or resulting documentation.

WHAT ARE THE POTENTIAL BENEFITS?

You will not benefit directly from taking part in this research. However, the knowledge gained from this study may contribute to our understanding of hospital vulnerability and lead to improved survivability of health care operations during disaster events.

HOW WILL CONFIDENTIALITY BE MAINTAINED?

We will make every effort to keep all research records that identify you confidential to the extent permitted by law. In the event of any publication or presentation resulting from the research, no personally identifiable information will be shared.

Your research records may be viewed by the University of Delaware Institutional Review Board, but the confidentiality of your records will be protected to the extent permitted by law.

WILL THERE BE ANY COSTS RELATED TO THE RESEARCH?

There are no costs associated with participating in this study.

WILL THERE BE ANY COMPENSATION FOR PARTICIPATION?

There is no compensation association with participating in this study.

DO YOU HAVE TO TAKE PART IN THIS STUDY?

Taking part in this research study is entirely voluntary. You do not have to participate in this research. If you choose to take part, you have the right to stop at any time. If you decide not to participate or if you decide to stop taking part in the research at a later date, there will be no penalty or loss of benefits to which you are otherwise entitled. Your refusal will not influence current or future relationships with the University of Delaware or the U.S. Government.

WHO SHOULD YOU CALL IF YOU HAVE QUESTIONS OR CONCERNS?
If you have any questions about this study, please contact the Principal Investigator, James Goetschius at [phone number] or [email address].

If you have any questions or concerns about your rights as a research participant, you may contact the University of Delaware Institutional Review Board at 302-831-2137.

Your signature below indicates that you are agreeing to take part in this research study. You have been informed about the study's purpose, procedures, possible risks and benefits. You have been given the opportunity to ask questions about the research and those questions have been answered. You will be given a copy of this consent form to keep.

By signing this consent form, you indicate that you voluntarily agree to participate in this study.

______________________________ ______________
Signature of Participant Date

____
Printed Name of Participant

Appendix K

INFLUENCE DIAGRAM INTERVIEW GUIDE FOR EXPERT PANEL

The purpose of this expert panel is to better understand the factors that bear on hospital functionality. We wish to identify the wide range of elements that affect a hospital's ability to provide medical services and the influences those elements have on the provision of health care. The panel will begin with a presentation of a draft influence diagram depicting some elements and their influences. After the presentation, relevant questions will be asked to evaluate the model, its completeness, and its relevance.

We will start by asking you to briefly introduce yourself - in one minute or less - by telling the group:

1. Your name
2. Your position
3. Your organization
4. An experience you had with planning for or responding to the disruption of hospital functionality

The following is a list of questions and issues we will address during the next two hours. We are not looking for consensus. Every opinion is valuable, and we welcome different points of view on these issues.

1. The "structural system" consists of those building components necessary for maintaining the building's integrity against gravity, uplift, and lateral forces. What might happen if part of the structural system is damaged? How could it affect nonstructural systems? Functional systems? Hospital services?

2. How do you characterize hospital functionality?

3. How would you describe a comprehensive model of hospital functionality? What would be included? What could be excluded?

4. Can you identify other elements or influences that bear on hospital functionality beyond those identified in the draft influence diagram?

5. How comprehensive do we need to be when identifying elements and influences that affect hospital functionality? Consider the breadth and depth of internal and external factors. For example, how much of the supply chain should be included, and how deeply into the subcomponents of the electrical system should we delve?

6. How well does the model capture elements and influences outside the facility that affect hospital functionality?

7. How well does the model capture elements and influences inside the facility that affect hospital functionality?

8. How well does the model capture the goals and characteristics of effectiveness that affect hospital functionality?

9. How do you envision this model could be utilized during hospital project planning? Hospital design? Hospital hazard vulnerability analysis?

10. Is there anything we did not cover that you wish to address or anything you want to expand upon?

Additional/Alternate questions:

1. Can you identify other elements that bear on hospital functionality?

2. Can you identify other influences that bear on hospital functionality?

3. How broadly should we look when considering elements and influences that affect hospital functionality?

4. How specifically should we look when considering elements and influences that affect hospital functionality?

5. How is the influence diagram useful for understanding the elements that influence hospital functionality? What is not included in the diagram?

6. How might this model improve hospital planning and design?

7. How might this model improve hospital disaster planning?

Appendix L

HVMF INTERVIEW GUIDE FOR EXPERT PANEL

The purpose of this expert panel is to better understand the factors that bear on hospital vulnerability. We wish to identify the wide range of elements that affect a hospital's ability to provide medical services and the influences those elements have on the provision of health care. The panel will begin with a presentation of a draft hazard vulnerability analysis framework. After the presentation, relevant questions will be asked to evaluate the framework, its completeness, and its relevance.

We will start by asking you to briefly introduce yourself - in one minute or less - by telling the group:

1. Your name
2. Your position
3. Your organization
4. An experience you had with planning for or responding to the disruption of hospital functionality

The following is a list of questions and issues we will address during the next two hours. We are not looking for consensus. Every opinion is valuable, and we welcome different points of view on these issues.

1. How do you characterize hospital vulnerability?

2. How well does the model capture the range of hazards that threaten hospitals?

3. How well does the model capture the factors that describe hazard agents and characteristics?

4. How well does the model capture the hospital and hospital dependent elements that are exposed to hazards and their agents?

5. How well does the model capture the characteristics of vulnerability that threaten hospital functionality?

6. How well does the model capture the nature of consequences from hospital vulnerabilities?

7. How well does the model describe the characteristics of mitigation and preparedness activities in hospitals?

8. Can you identify other elements or characteristics that bear on hospital vulnerability?

9. How do you envision this model could be utilized during hospital project planning? Hospital design? Hospital hazard vulnerability analysis?

10. Is there anything we did not cover that you wish to address or anything you want to expand upon?

Additional/Alternate questions:

1. How broadly should we look when considering elements and influences that affect hospital vulnerability?

2. How specifically should we look when considering elements and influences that affect hospital vulnerability?

3. How well does the model capture elements and influences outside the facility that affect hospital vulnerability?

4. How well does the model capture elements and influences inside the facility that affect hospital vulnerability?

5. How would you describe a comprehensive model of hospital vulnerability? What would be included? What could be excluded?

6. How might this model improve hospital planning and design?

7. How might this model improve hospital disaster planning?

8. How have you conducted hospital HVA's in the past? What information/sources were important for understanding hazards and vulnerabilities?

9. How have HVA's been incorporated into planning and design efforts in the past?

10. How might this framework improve hospital planning and design?

11. Is the HVA framework useful for understanding the hazards and vulnerabilities that threaten hospitals? Is it useful for understanding the mitigation and preparedness actions that reduces a hospital's risk exposure?

Appendix M

APPROVAL LETTER FOR USE OF HOSPITAL REHABILITATION, IMPEDIMENTS, AND INCENTIVES PROJECT DATA

UNIVERSITY OF DELAWARE | DRC

Disaster Research Center
166 Graham Hall
Newark, DE 19716
Phone (302) 831-6618
FAX (302) 831-2091

March 18, 2013

Institutional Review Board
University of Delaware
Newark, DE 19716

Dear Colleagues:

I was the Principle Investigator for the research grant, "Hospital Rehabilitation, Impediments, and Incentives Project," funded by NSF through SUNY, Buffalo's Multidisciplinary Center for Earthquake Engineering Research (MCEER). That project focused on earthquake preparedness and mitigation at hospitals in California, New York, and Tennessee in 2000 and 2001.

I am giving **James Goetschius**, a PhD student in the Disaster Science and Management program, permission to utilize the data—focus group interviews, qualitative and quantitative data, and documents--gathered during this project for his dissertation work. Jim has obtained his Certificate of Training in Human Subjects Research, taken the Responsible Conduct of Research course, and signed the Disaster Research Center's Confidentiality of Information Sources form (required of all research staff at DRC). His Human Subjects Protocol will specify how these data will be used and what additional data he intends to collect.

If you have any questions, please don't hesitate to contact me (nigg@udel.edu).

Respectfully,

Joanne M. Nigg

Joanne M. Nigg, PhD
Professor

Appendix N

INTERVIEW GUIDE FOR HOSPITAL REHABILITATION, IMPEDIMENTS, AND INCENTIVES PROJECT

1. First, could (each of) you tell me what your position at the medical center is and how it is related to disaster preparedness or the safety of the facility?

2. What is this hospital's role in a community-wide (or larger) mass emergency or disaster; that is, what do you expect the medical center to be doing in such an event? (PROBE: Is this a specific part of the city's/ county's disaster plan?)

3a. How would you define "normal" functionality of the hospital? That is, what is a routine inpatient load, a routine out patient load, what are your routine staffing requirements, etc.?

3b. What types of non-disaster emergencies have you experienced over the last three years that have challenged the routine functionality of the hospital?

3c. What type of event triggers activation of the hospital's disaster plan; that is, does an event need to be of a certain size in order for the hospital to activate its plan?

4a. We know that there are state agencies and national organizations (such as The Joint Commission) that regulate or require hospitals to prepare themselves for a disaster. Can you tell us how has this facility met those requirements?

4b. Does this hospital offer any teaching programs? If so, are there any requirements for disaster preparedness training in those programs?

4c. Is this hospital designated as a trauma center? Are there certain guidelines or standards that the hospital must follow in order to get that designation? (PROBE: What organization sets these standards/requirements?).

5a. What are the major natural, technological and/or human-caused disasters that you believe could affect this hospital? That is, what disaster events do you plan for? And what types of threats do you try to protect the facility from?

5b. What types of internal or on-site disasters are most likely to occur? That is, what types of internal events do you plan for?

6. What types of measures have been taken to lessen damage and loss of function in the event that one of those disasters struck this area, including the hospital itself? (PROBE: Which ones are aimed at reducing damage, and which ones are aimed at maintaining functionality?)

7. Obviously, large medical centers like this one face many different types of pressures—upgrading equipment and facilities, hiring new staff, keeping up with technological and scientific advances in health care, meeting patient expectations, and controlling costs among other things. On a scale of 1-10 where "1" indicates the issue has a very high priority and "10" indicates that the issue probably isn't even under consideration, please tell me where you would rank the following issues. (PROBE FULLY TO UNDERSTAND WHY SOMETHING IS HIGH OR LOW PRIORITY):
A. Disaster response planning.
B. Disaster preparedness training— preparing the staff to meet challenges produced by disaster situations.
C. Disaster preparedness—getting ready to deal with the potential failure of external utility systems (back-up generators, etc.).
D. Conducting hazard/risk assessments of the physical facility to identify potential structural and non-structural problems that could occur in a disaster.
E. Investing in rehabilitating or retrofitting non-structural systems or structural elements to ensure they would not fail.

8. Now, to this list of internal systems we have added some structural elements that have affected the ability of a hospital to function following a disaster. As you know, building codes change from time to time with respect to structural and non-structural elements in facilities such as hospitals. In 2000, for example, there will be a standardized ICC that merges existing codes. Looking at the list of internal physical systems and structural elements on the last page of the questionnaire, please indicate—to the best of your knowledge—which systems have already had a hazard or risk analysis performed and which ones will need to be performed in order to meet the requirements of the new code. (PROBE: Have any assessments been made with respect to recent expansions or remodeling efforts?)

9. In addition to what we have already talked about, are there any other things that hospitals must consider in disaster preparedness and response planning that are important?

10. Do you have copies of any disaster plans for the hospital or any reports that would help us better understand how hospitals prepare for and respond to disasters?

Appendix O

HOSPITAL SERVICES SURVEY

We know that medical centers (especially large ones like this) have a number of different units, all of which are needed to keep the facility operating normally. But in times of disasters, hospitals often have to make crucial decisions about what they can continue to do given the impacts they experience. Here is a list of functional units in a hospital (and there may be others that you want to add to this list). In order for (FACILITY NAME) to remain operational and functioning during and immediately following a disaster impact, could you please identify—on a seven-point scale—how essential each of these units is. A "1" would mean that it is essential for that unit to remain open and able to provide service; a "7" would indicate that the unit is not essential—at least during the emergency period—for the hospital to protect its patients and provide service to the injured in the surrounding communities.

FUNCTIONAL UNITS IN HEALTH CARE FACILITIES

Medical Systems	Essential					Not Essential	
1. Trauma/Emergency department	1	2	3	4	5	6	7
2. Operating rooms	1	2	3	4	5	6	7
3. Recovery rooms	1	2	3	4	5	6	7
4. ICU/CCU	1	2	3	4	5	6	7
5. NICU	1	2	3	4	5	6	7
6. Central supply	1	2	3	4	5	6	7
7. Blood bank	1	2	3	4	5	6	7
8. Ob/Gyn	1	2	3	4	5	6	7

Diagnostic Systems	Essential					Not Essential	
9. Laboratories	1	2	3	4	5	6	7
10. Radiology	1	2	3	4	5	6	7
11. Imaging (MRI/CT Scan)	1	2	3	4	5	6	7

Patient Support Systems	Essential					Not Essential	
12. Nursing care units	1	2	3	4	5	6	7
13. Pharmacy	1	2	3	4	5	6	7
14. Housekeeping	1	2	3	4	5	6	7
15. Medical records/Patient info	1	2	3	4	5	6	7
16. Laundry	1	2	3	4	5	6	7

17. Dietary	1	2	3	4	5	6	7

Looking back over the list above, choose three functional units that you believe must remain functional and continue to operate in the event of a major disaster. Write the number that corresponds to each of those three most important units in the spaces below. For example, if you believe "Radiology" is among the five most important, write "10" in one of the spaces.

__________ __________ __________

Appendix P

NONSTRUCTURAL SYSTEMS SURVEY

Large, complex medical facilities–like this one–have a variety of internal physical systems that support the general activities of the hospital. Here is a list of internal systems. Please identify, again using the 7-point scale, how important each of these is in order for the hospital to remain functional in and following a disaster event; that is, if the system were damaged or failed to function normally, the hospital would not be able to carry out its activities. (PLEASE FEEL FREE TO ADD OTHER SYSTEMS TO THIS LIST)

INTERNAL PHYSICAL SYSTEMS

	Very Important						Not Very Important
1. Air conditioning	1	2	3	4	5	6	7
2. Heating	1	2	3	4	5	6	7
3. Ventilation	1	2	3	4	5	6	7
4. Refrigeration	1	2	3	4	5	6	7
5. Medical gases	1	2	3	4	5	6	7
6. Steam for sterilization	1	2	3	4	5	6	7
7. Fire piping and sprinklers	1	2	3	4	5	6	7
8. Fire alarms	1	2	3	4	5	6	7
9. Plumbing	1	2	3	4	5	6	7
10. Electrical	1	2	3	4	5	6	7
11. Communications	1	2	3	4	5	6	7
12. Computer terminals/servers	1	2	3	4	5	6	7

13. Lighting	1	2	3	4	5	6	7

Looking back over the list above, choose three types of systems that you believe must remain functional and continue to operate in the event of a major disaster. Write the number that corresponds to each of the three most important systems in the spaces below. For example, if you believe that "Refrigeration" is among the five most important systems, write "4" in one of the spaces.

__________ __________ __________

Appendix Q

EXTERNAL LIFELINES SURVEY

For hospital units to remain functioning at a normal or near-normal level, several types of systems are necessary. Here is a list of utility systems that originate outside of the hospital. Please indicate how important it is–on a seven-point scale–for each of them to remain functional in a disaster; that is if the system were damaged or failed to function normally, the hospital would not be able to carry out its activities. A “1" means that the system is “very important” and a “7" means that the failure of the system would have little impact on the hospital. (PLEASE FEEL FREE TO ADD OTHER EXTERNAL SYSTEMS TO THIS LIST)

EXTERNAL LIFELINE SYSTEMS

	Very Important				Not Very Important		
1. Transportation routes to the facility	1	2	3	4	5	6	7
2. Electrical power	1	2	3	4	5	6	7
3. Water supply	1	2	3	4	5	6	7
4. Sewage/wastewater discharge	1	2	3	4	5	6	7
5. Natural gas	1	2	3	4	5	6	7
6. Telephone service	1	2	3	4	5	6	7
7. Data communications (satellite, microwave, shortwave)	1	2	3	4	5	6	7

Looking back over the list above, choose three types of systems that you believe must remain functional and continue to operate in the event of a major disaster. Write the number that corresponds to each of the five most important systems in the spaces below. For example, if you believe that "Natural gas" is among the three most important systems, write "5" in one of the spaces.

__________ __________ __________

Appendix R

HOSPITAL SERVICES QUANTITATIVE ANALYSIS

R.1 Introduction

The quantitative analysis of hospital services evaluates how hospital staff members from the Hospital Rehabilitation, Impediments, and Incentives Project rated the essentialness of various services to hospital operations and functionality in the first 72-hours of a disaster. This appendix begins with a comparison of the hospital hazard mitigation project ratings to those reported by the California Building Safety Board (Holmes, 2002) and the Pan American Health Organization (2000). Then, the service-level analysis of the hospital hazard mitigation project is presented with histograms and narrative explaining the findings.

R.2 Comparative Analysis

Recognizing that some hospital functions are more critical than others during a disruptive event, numerous researchers and organizations have attempted to discern which services are the most important and should receive added attention during disaster planning and preparation. This section compares the ratings of three such efforts.

In addition to reporting the raw scores of importance for each of the studies, I calculated z-scores to standardize the distributions for each measure of hospital service importance to hospital functionality. Each of the studies used a different scale to measure importance. To compare the raw scores between them is difficult, but by normalizing the scores, we are able to see where they fall in the distribution and compare that position to the mean. This makes comparing the distributions for the three scales possible.

To calculate the z-scores, I used the formula:

$$z = \frac{X - M}{s}$$

I used Microsoft Excel 2010 to calculate the scores. The numerator is determined by subtracting the mean (M) from the raw score (X), which produces the deviation score and indicates whether X is above or below the mean. The deviation score is divided by the standard deviation (s) to show where the raw score exists in the distribution in terms of the standard deviation. Thus, a z-score of +2.0 indicates the raw score is two standard deviations above the mean in the distribution (Gravetter & Wallnau, 2011).

The values used to calculate the means and standard deviations were taken from the summary of sample data because the population data was not available. Page and Patton (1991) suggest that using sample data for these is acceptable when the sample size is at least 30. However, the sample sizes for two of the three studies were not known. The values from the California Building Safety Board and PAHO were summary values (single values applied to each hospital service). To equate the Hospital Rehabilitation, Impediments, and Incentives project values with the other two studies, I calculated means from the 76 respondents to represent the importance of each service to hospital functionality following a disaster event. The z-scores calculated from these summary values allow us to compare the importance of particular services against the relative importance of the same services in the other studies.

R.2.1 Hospital Rehabilitation, Impediments, and Incentives Project

An element of the hospital hazard mitigation project was asking the respondents to score 17 hospital services on their essentialness to maintaining hospital operations and functionality within the first 72-hours of a disaster event. The ratings were given on a 7-point scale from essential (1) to not essential (7). Table R.1 identifies the mean essentialness ratings for each of the services and the normalized value for comparison to the relative importance ratings reported by Holmes (2002) and the ratings reported by the PAHO (2000).

Table R.1: Essentialness of Hospital Services

Hospital Services	Mean Essentialness	z-score
Trauma/Emergency	1.12	-1.28
Blood Bank	1.29	-1.08
Operating Rooms	1.36	-1.00
Intensive Care Unit / Critical Care Unit	1.49	-0.84
Laboratory	1.57	-0.75
Radiology	1.58	-0.73
Nursing Care Units	1.64	-0.66
Pharmacy	1.70	-0.59
Recovery	2.04	-0.18
Central Supply	2.10	-0.11
Imaging	2.34	0.18
Dietary	2.58	0.47
Neonatal Intensive Care Unit	2.80	0.74
Housekeeping	3.08	1.07
Medical Records	3.34	1.39
Obstetrics / Gynecology	3.56	1.65
Laundry	3.62	1.72
Essentialness was measured on a 7-point scale where 1 was “essential” and 7 was “not essential.”		

R.2.2 California Building Safety Board

As part of an effort to quantify the seismic risk faced by hospitals not in compliance with California's building codes, the state's Building Safety Board identified critical health care functions. Those services were assigned values representing their relative importance in the delivery of disaster related health care. Then, the numbers were included in the calculations to prioritize facilities for seismic retrofit (Holmes, 2002). Four of the ten services identified were given the highest rating, while two received the second highest rating. Table R.2 identifies the relative importance ratings for each of the services and the normalized value for comparison to the hospital hazards mitigation project and the ratings reported by the PAHO (2000).

Table R.2: Relative Importance of Hospital Services (Holmes, 2002)

Hospital Services	Relative Importance	z-score
Trauma/Emergency (called Emergency Room)	0.2	-0.97
Operating Rooms (called Surgery)	0.2	-0.97
Intensive Care Unit / Critical Care Unit (called Critical Care Beds: Each 12 beds or fraction thereof)	0.2	-0.97
Obstetrics / Gynecology (called Labor and Delivery)	0.2	-0.97
Laboratory	0.15	-0.22
Radiology	0.15	-0.22
Nursing Care Units (called Beds other than Critical Care: Each 50 beds or fraction thereof)	0.1	0.52
Pharmacy	0.05	1.27
Dietary	0.05	1.27
General Storage, Required	0.05	1.27
Relative importance was measured between 0.20 and 0.05. The higher the value, the greater the relative importance.		

R.2.3 Pan American Health Organization

The Pan American Health Organization (2000) identified 31 hospital services deemed important during an emergency. The list was modified from research done by Boroschek, Astroza, and Osorio (1996). Of the rankings included in this analysis, it lists the largest number of services. It is also the only one to include medical specialties other than obstetrics and gynecology. Eleven activities received the top score, indicating they are indispensable. Six services were identified as very necessary and four as necessary. Table R.3 identifies the importance rankings for each of the services and the normalized value for comparison to the hospital hazards mitigation project and the relative importance scores reported by Holmes (2002).

Table R.3: Importance of Hospital Services (PAHO, 2000)

Hospital Services	Importance	z-score
Trauma/Emergency (called two items: 1. Trauma and Orthopedics; 2. Emergency Care)	5	-1.07
Blood Bank	5	-1.07
Intensive Care Unit / Critical Care Unit (called Intensive Care Unit / Intensive Treatment Unit)	5	-1.07
Radiology (called Diagnostic Imaging)	5	-1.07
Pharmacy	5	-1.07
Recovery	5	-1.07
Dietary	5	-1.07
Urology	5	-1.07
Sterilization	5	-1.07
Transport	5	-1.07
Laboratory	4	-0.43
Laundry	4	-0.43
Outpatient Consultation / Admissions	4	-0.43
Pediatric Surgery	4	-0.43
Pediatrics	4	-0.43

Table R.3 continued

Hemodialysis	4	-0.43
Obstetrics / Gynecology	3	0.21
Internal Medicine	3	0.21
Administration	3	0.21
Neonatology	3	0.21
Respiratory Medicine	2	0.85
Neurology	2	0.85
Ophthalmology	2	0.85
Filing and Case Management	2	0.85
Dermatology	1	1.49
Psychiatry	1	1.49
Oncology	1	1.49
Otorhinolaryngology	1	1.49
Dental Services	1	1.49
Therapy and Rehabilitation	1	1.49
Importance was measured on a 5-point scale where 1 was “indispensable,” 2 was “very necessary,” 3 was “necessary,” 4 was “preferable,” and 5 was “dispensable.”		

Among the three rating efforts, eight services are reflected on all of them: trauma/emergency, operating rooms, intensive/critical care, obstetrics/gynecology, laboratory, radiology, pharmacy, and dietary. Trauma/emergency is recognized as most important on all three. The operating rooms and intensive/critical care are also at, or near, the top of all three. Obstetrics/gynecology is less clear. The California Building Safety Board rated labor and delivery among the most important, while the other two ranked it less importantly. Laboratory is recognized as important by all three. Radiology is rated as important by all three, but PAHO gives it the highest rating. Pharmacy received the highest rating by the hospital mitigation project and PAHO. Finally, dietary was recognized as indispensable by PAHO, but it was less important in the other two ratings.

The three ratings use different scales for evaluating the importance of the hospital services. While the scores have been normalized for the comparison, it is possible that the terms used to describe the ends of each scale influenced how the respondents scored each service. Given the opportunity to review the three scales, the respondents may not consider “essential” and “indispensable” or “not essential” and “dispensable” to be synonymous. If that is the case, the comparison may be flawed. A rating tool with clear definitions for the services and a descriptive scale (more in line with that used by PAHO) administered to a larger sample may provide clearer results.

R.3 Service-level Analysis

This section addresses the service-level analysis performed on the data gathered by the Hospital Rehabilitation, Impediments, and Incentives Project. The respondents were asked to assign a value of one to seven, from “essential” to “not essential” to each of 17 hospital services based on the essentialness of those functions in maintaining hospital operations and functionality within 72-hours of a disaster.

In addition, the participants identified, in order, the three services they felt were most important. Figure R.1 shows that emergency and surgery were deemed to be the most important hospital services when ranked against the other services. The services that received ten or more total votes were all either treatment or ancillary services. Support services received very few mentions.

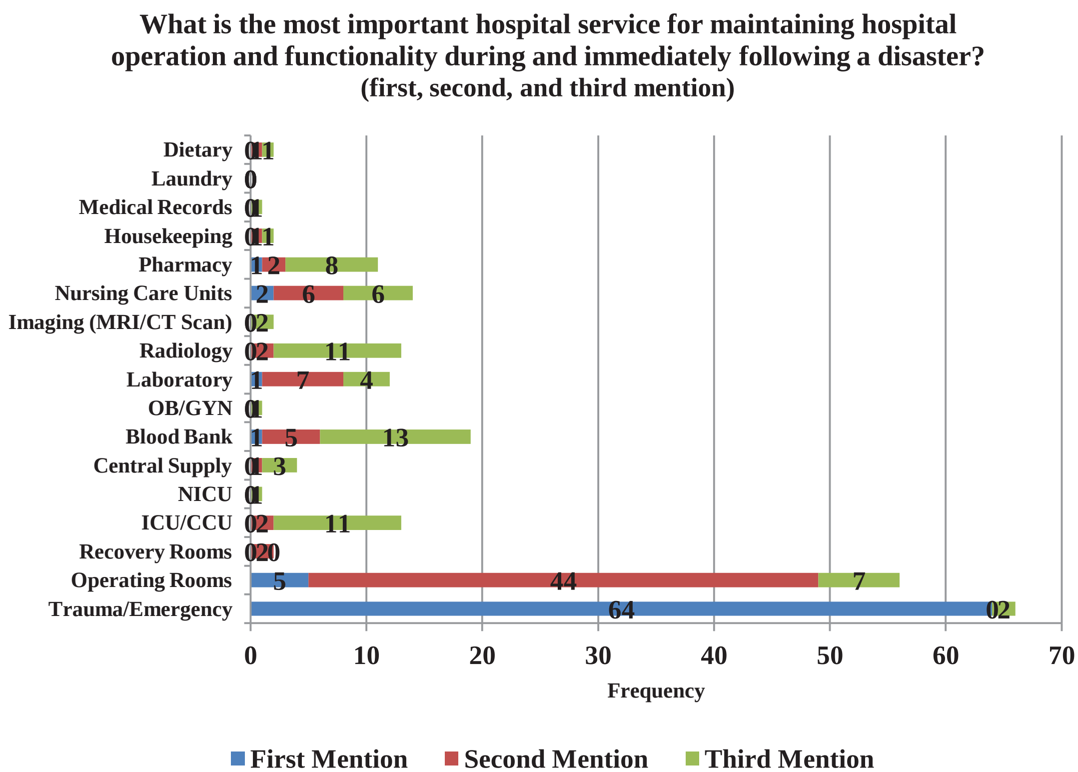

Figure R.1: The Most Important Hospital Services

R.3.1 Trauma and Emergency

Figure R.2 shows that a large majority of respondents considered hospital trauma and emergency services to be essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Definitive trauma and emergency care is one of the services that separate hospitals from lower levels of care.

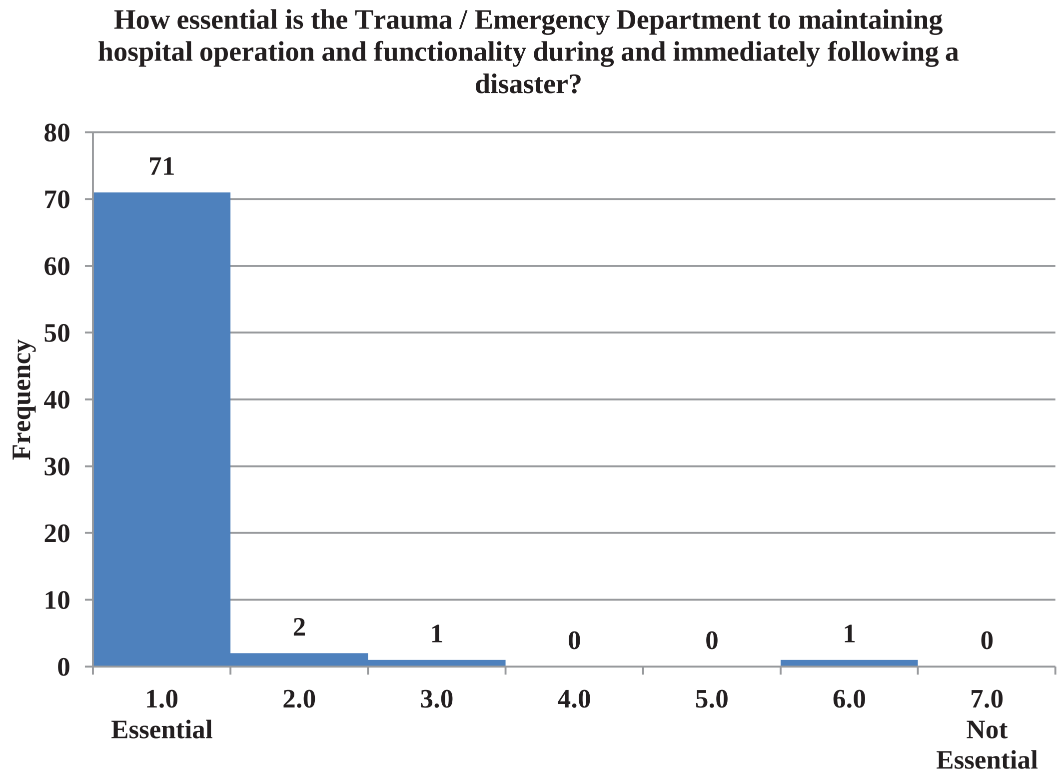

Figure R.2: Essentialness of Trauma and Emergency Services

R.3.2 Blood Bank

Figure R.3 shows a clear majority of respondents considered the blood bank to be essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. The blood bank is closely related to emergency and surgical care, particularly for patients who have experienced trauma.

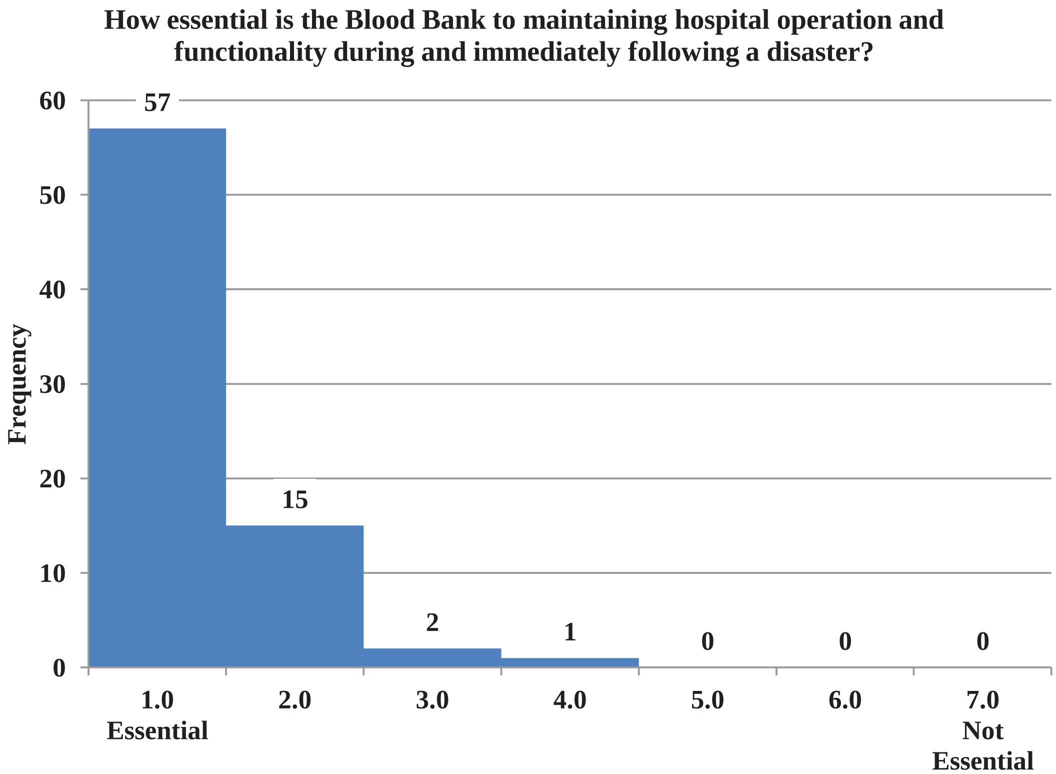

Figure R.3: Essentialness of the Blood Bank

R.3.3 Operating Rooms

Figure R.4 shows a significant majority of respondents considered surgical services to be essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Like trauma and emergency care, surgery is one of the services that separate hospitals from lower levels of care. Surgery is also frequently necessary to treat traumatic injuries and serious illnesses.

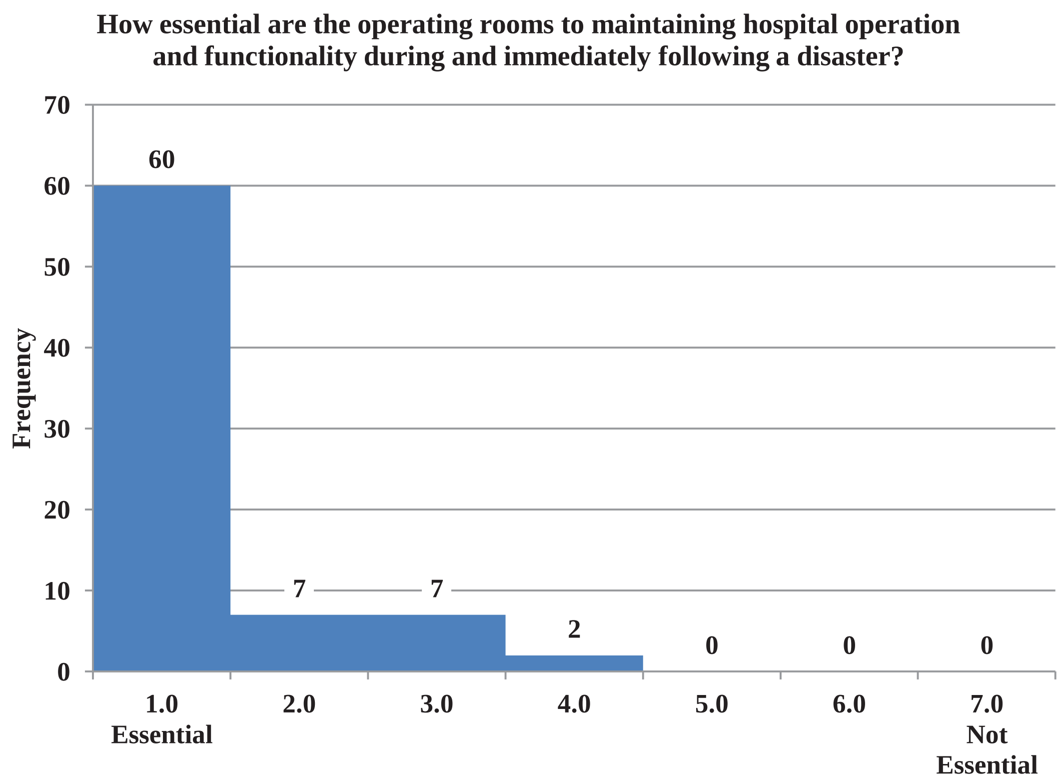

Figure R.4: Essentialness of Surgical Services

R.3.4 Intensive Care Unit / Critical Care Unit

Figure R.5 shows a majority of respondents considered intensive and critical care services to be essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. This high level of nursing care is typically reserved for the most critical patients and can commonly be found in tertiary and quaternary medical treatment facilities. If adequate staff, beds, and equipment are available, intensive and critical care units can also be used to monitor patients recovering from surgery.

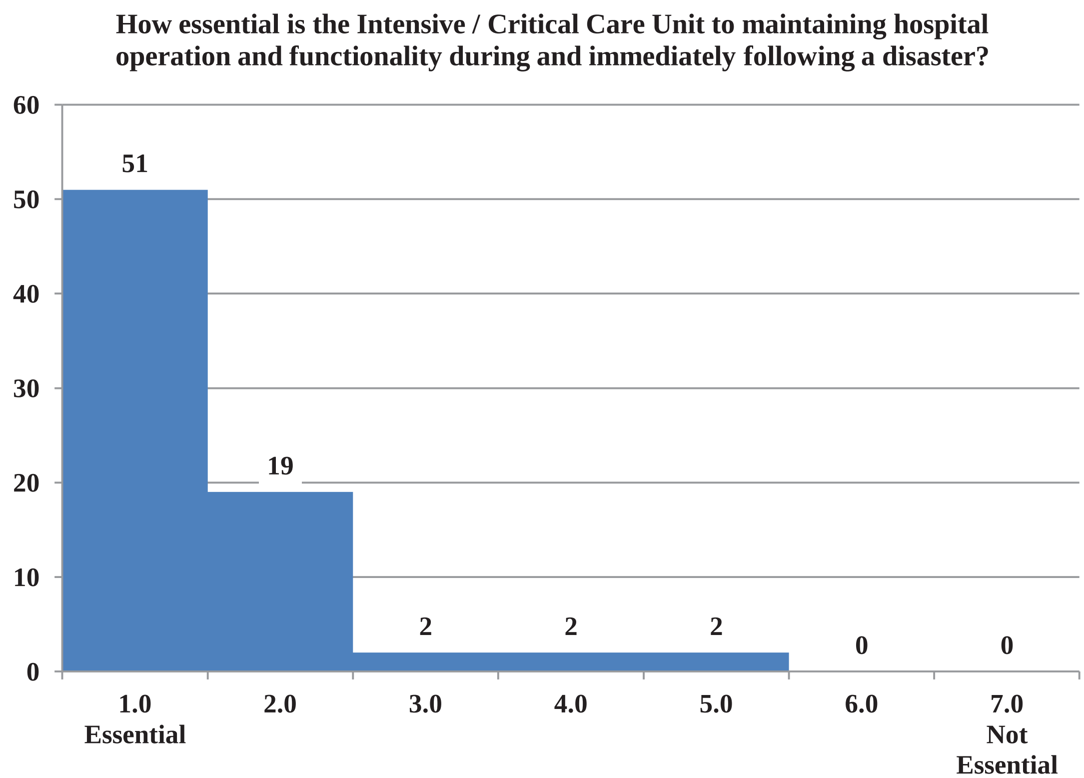

Figure R.5: Essentialness of Intensive and Critical Care

R.3.5 Laboratory

Figure R.6 shows a majority of respondents considered laboratory services to be essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. This ancillary service is frequently a key tool in diagnosing an illness. While some minor diagnostic tests may be available within departments, more complicated and definitive diagnostic tests are available in the laboratory.

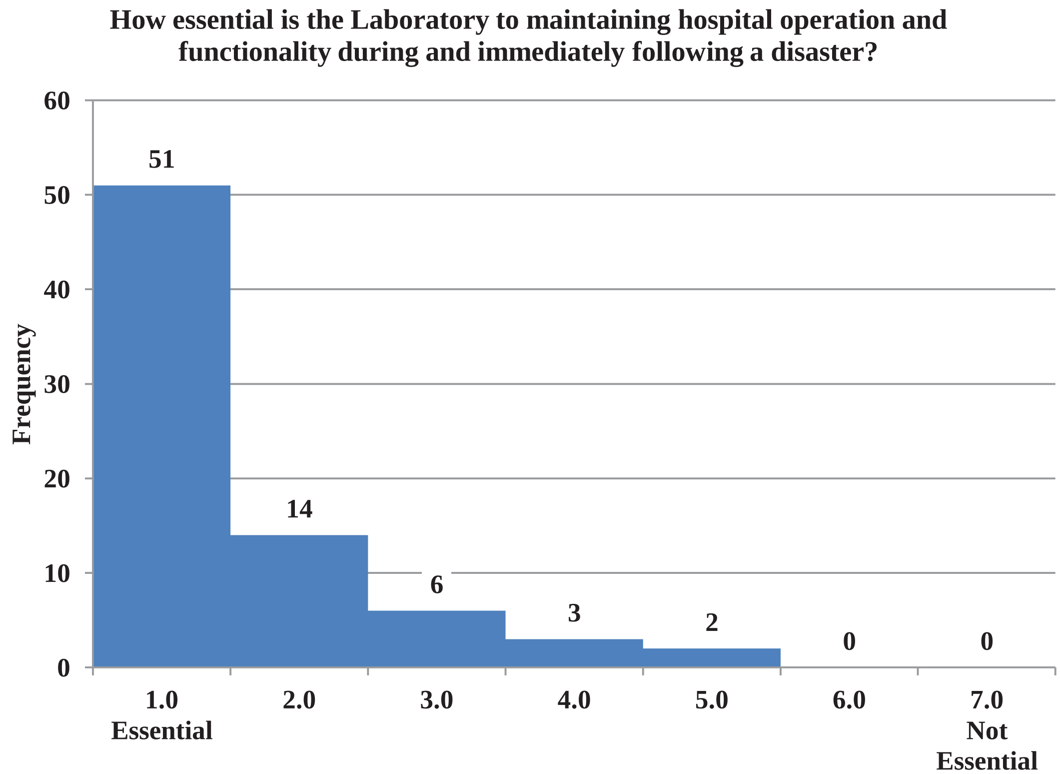

Figure R.6: Essentialness of the Laboratory

R.3.6 Radiology

Figure R.7 shows a majority of respondents considered radiologic services to be essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Radiology is an important diagnostic function used frequently by practitioners of emergency, surgical, and internal medicine, plus other specialties. Radiology departments frequently offer general x-rays, ultrasound, computed tomography, and magnetic resonance. However, for this survey, CT scanners and MRIs were listed separately under “Imaging.”

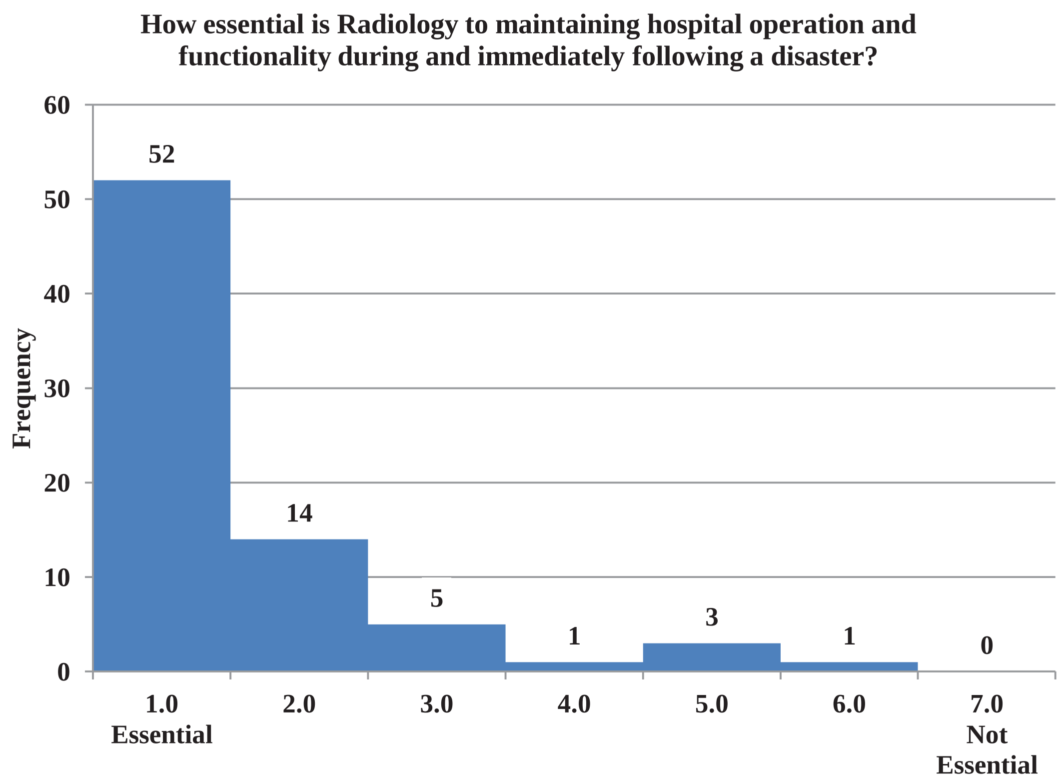

Figure R.7: Essentialness of Radiology

R.3.7 Nursing Care Units

Figure R.8 shows a majority of respondents considered nursing care units to be essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Based on the use of the term in the survey, and the lack of a definition, it is not clear if the respondents were equating nursing care units with medical-surgical (med-surg) wards, where hospitalized patients received regular nursing care, or skilled nursing care units, where patients no longer require hospitalization, but still need skilled services like rehabilitation or intravenous therapy.

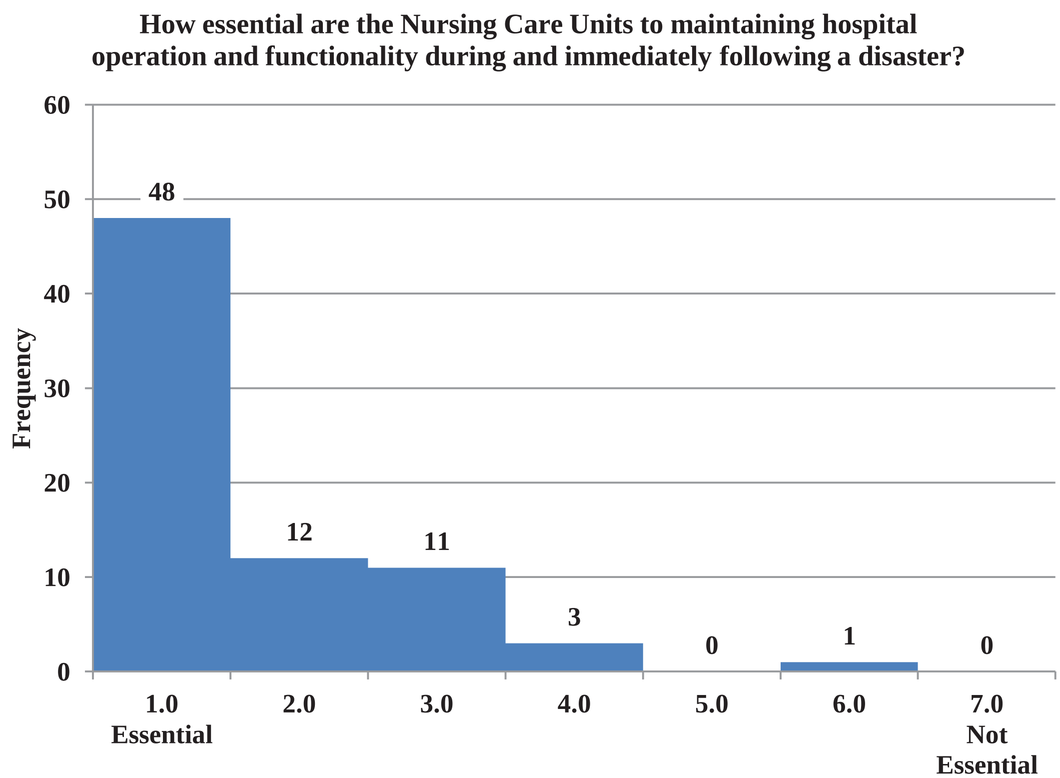

Figure R.8: Essentialness of Nursing Care Units

R.3.8 Pharmacy

Figure R.9 shows a majority of respondents considered pharmacological services to be essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. These therapeutic services are a key element of many health care treatments. Hospital pharmacies also frequently support community members when local pharmacies are closed during a disaster.

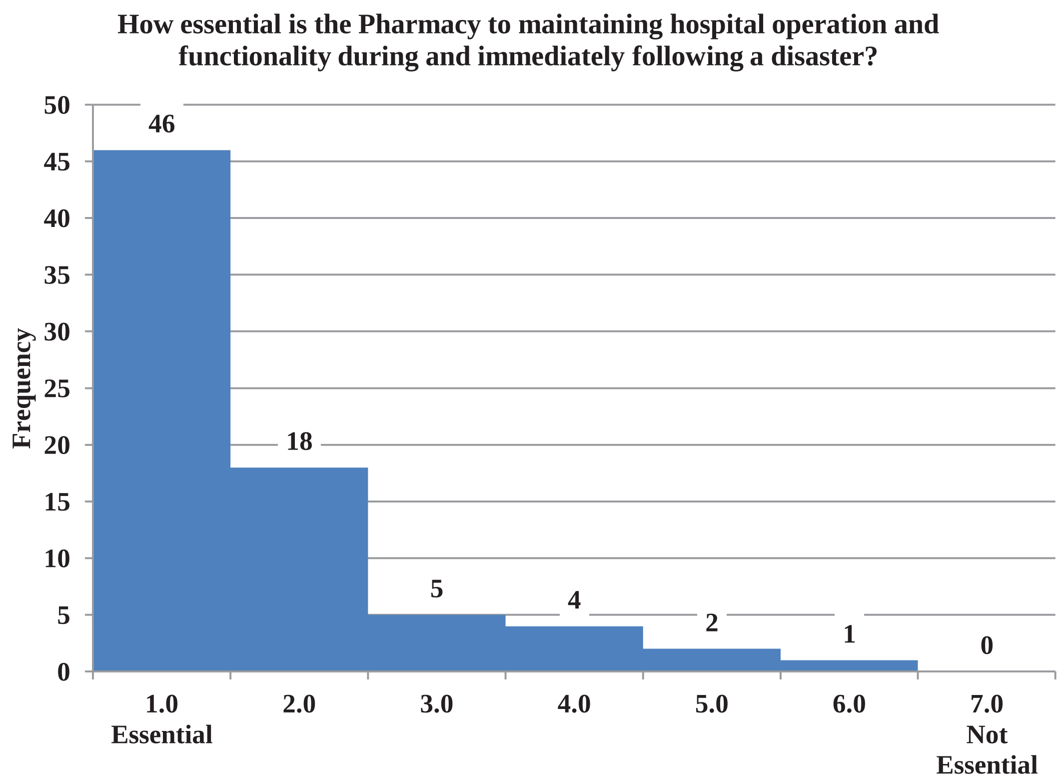

Figure R.9: Essentialness of the Pharmacy

R.3.9 Recovery

Figure R.10 shows a majority of respondents gave recovery rooms a score of 1 to 3 when determining whether they are essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Recovery rooms are a transition point between surgery and the intensive care unit or med-surg ward. With adequate staff and sufficient beds, these services could be performed in the ICU or on the wards.

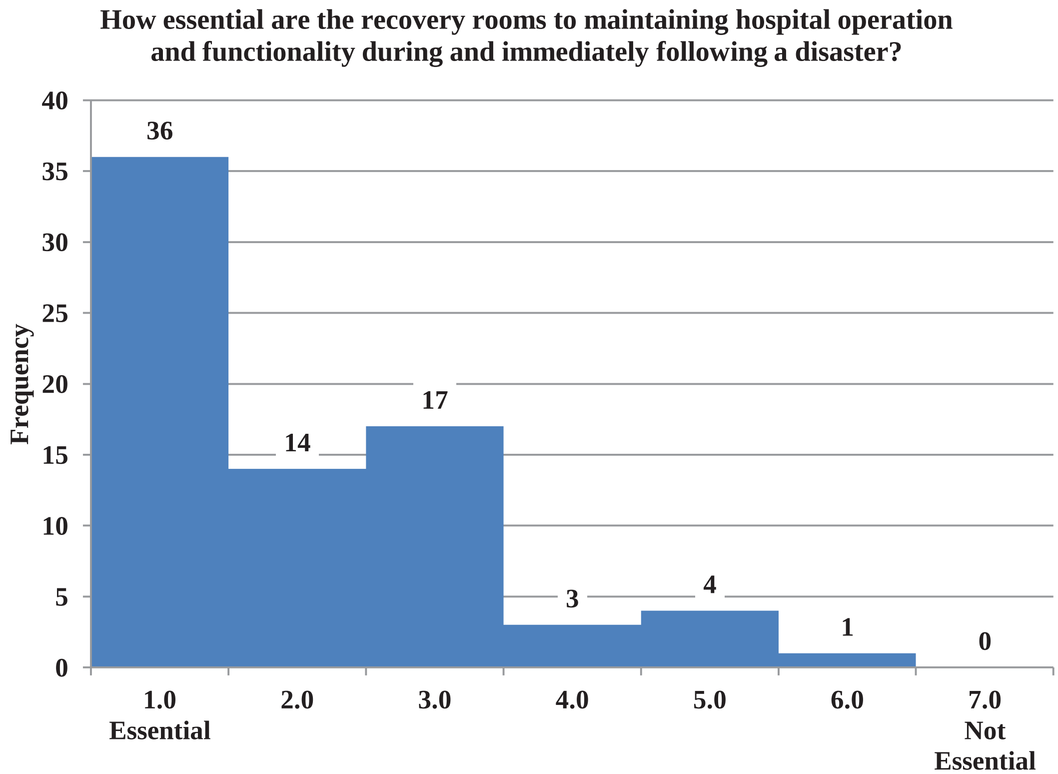

Figure R.10: Essentialness of Recovery Rooms

R.3.10 Central Supply

Figure R.11 shows a majority of respondents gave Central Supply a score of 1 to 3 when determining whether it is essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Based on the use of the term in the survey, and the lack of a definition, it is not clear if the respondents were considering the full scope of services offered by Central Supply, also known as Central Material Service. Beyond procurement and inventory management, Central Supply is also responsible for the bulk sterilization of surgical and medical equipment, the building of sterile packs, and storing materials used throughout the hospital.

It is possible the 72-hour timeframe associated with the survey affected the responses provided for these ratings. Unlike some services where a disruption would be felt immediately, the loss of Central Supply may not be felt for hours or days until the stocks of clean instruments and supplies are exhausted because they are not being replenished through the sterilization process. It is also possible that some hospitals are heavily reliant on external vendors to provide regular, just-in-time deliveries of many supplies, in which case the disruption to Central Supply was not considered a significant problem.

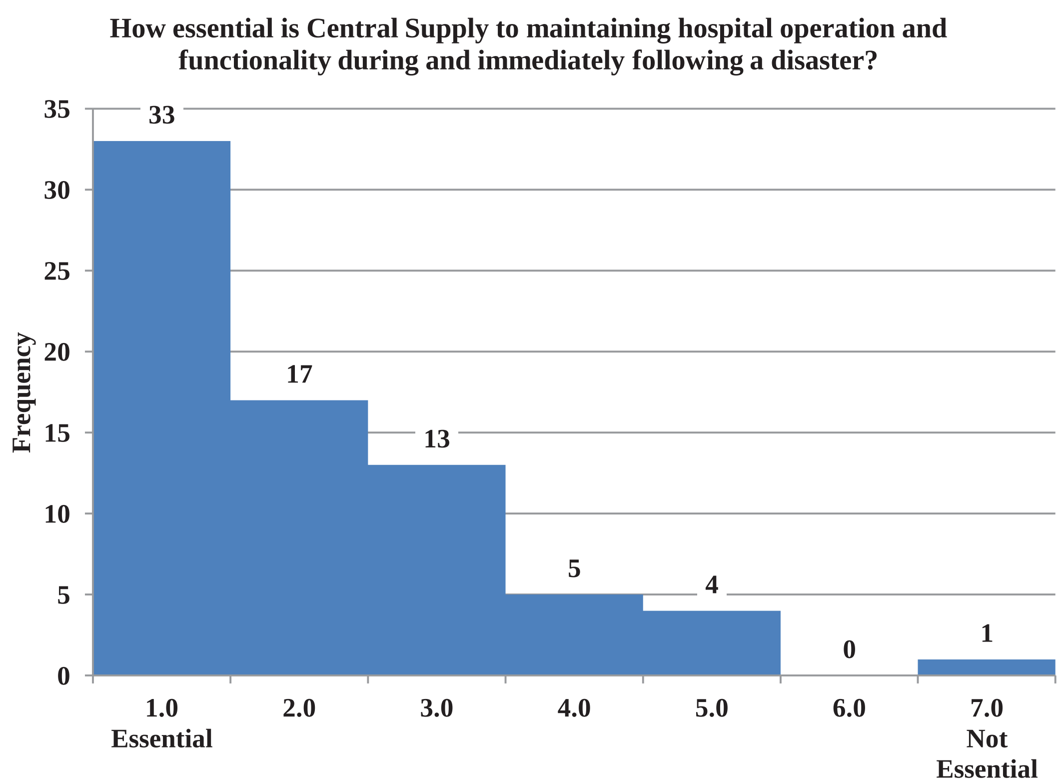

Figure R.11: Essentialness of Central Supply

R.3.11 Imaging

Figure R.12 shows a majority of respondents gave Imaging, which was described as computed tomography and magnetic resonance imaging, a score of 1 to 3 when determining whether it is essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. These advanced forms of diagnostic imaging are gaining in popularity and provide a level of detail not possible with traditional x-ray based radiological services. It is possible that their prevalence today would result in higher scores of essentialness if the survey were administered again.

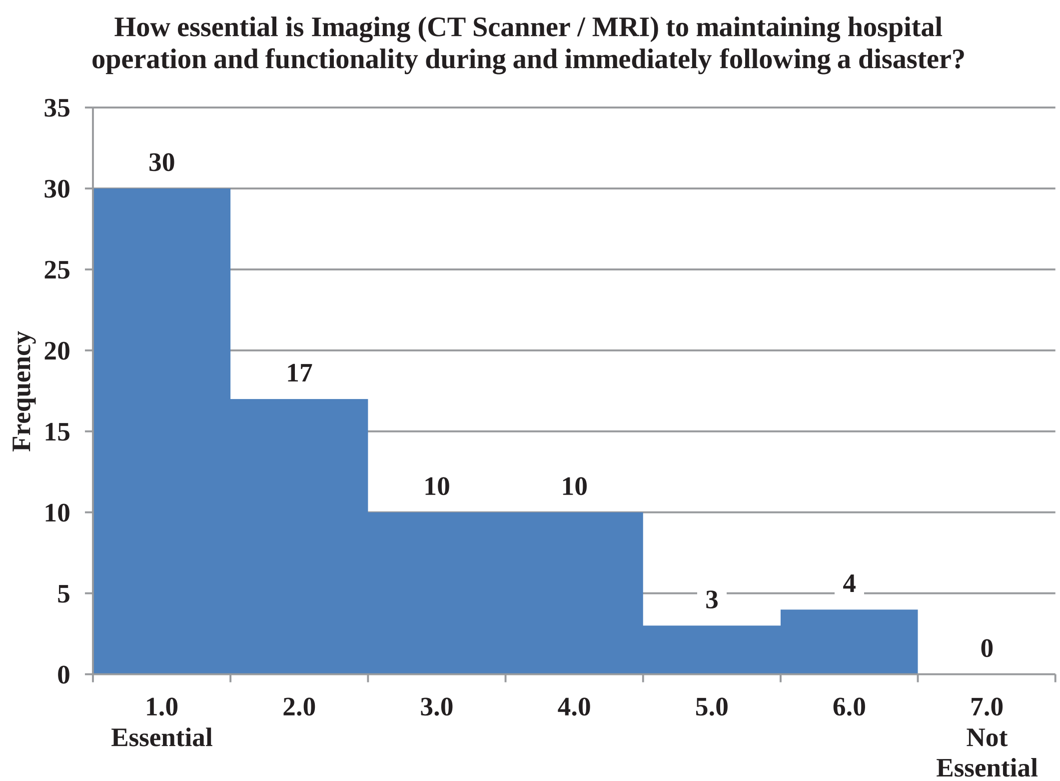

Figure R.12: Essentialness of Diagnostic Imaging

R.3.12 Dietary

Figure R.13 shows a majority of respondents gave dietary services a score of 1 to 3 when determining whether they are essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Based on the use of the term in the survey, and the lack of a definition, it is not clear if the respondents were equating Dietary with the feeding of patients and staff, the development of meal plans for inpatients, the monitoring of inpatient feedings, or something else. Without nutrition care, it is not clear how inpatients would be fed during the 72-hour timeframe identified in the survey. It is possible meals could be catered.

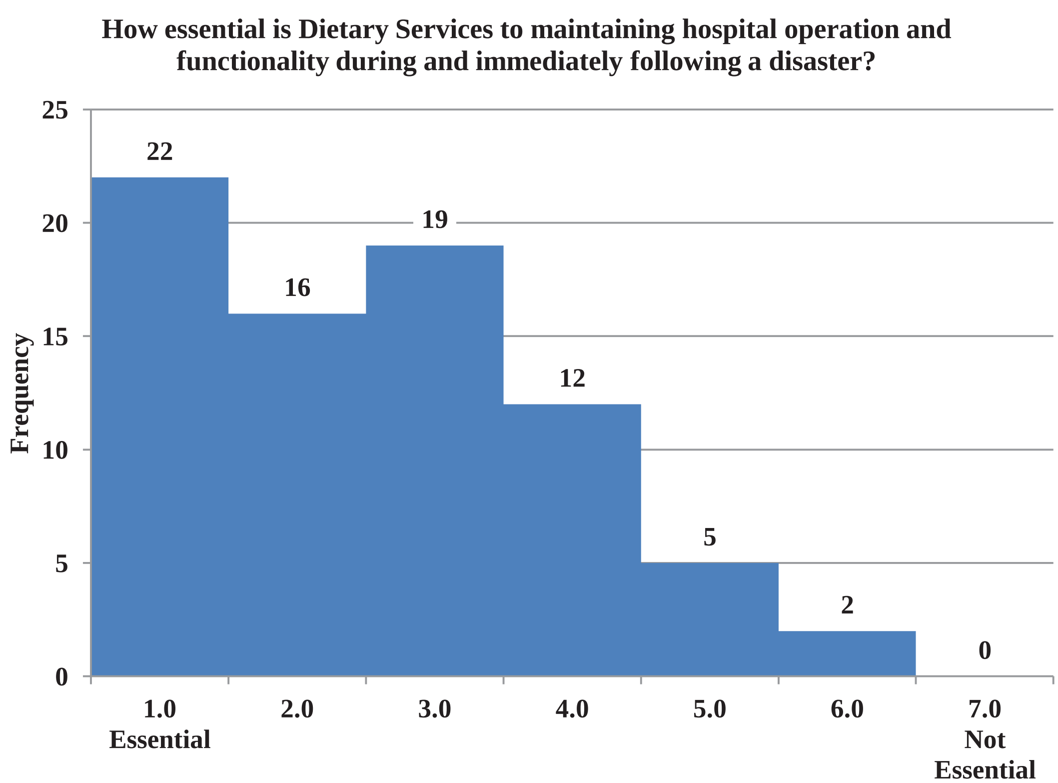

Figure R.13: Essentialness of Dietary Services

R.3.13 Neonatal Intensive Care Unit

Figure R.14 shows a majority of respondents gave the Neonatal Intensive Care Unit a score of 1 to 3 when determining whether they are essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. The number of respondents who did so is noticeably lower than the number who scored the Intensive Care Unit a 1 to 3. The fact that nine respondents gave the NICU a score of seven indicating that it is not essential is interesting. It is possible those respondents do not have a NICU in their facility. It is also possible they felt those patients could be transferred to the regular ICU during a disaster.

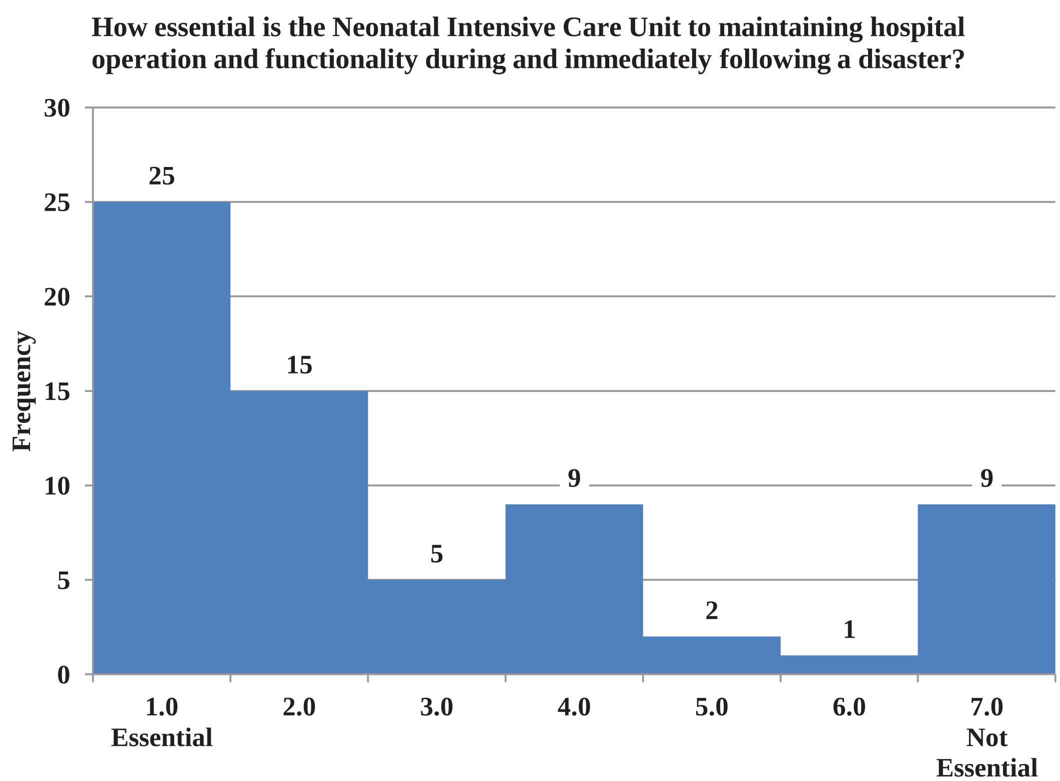

Figure R.14: Essentialness of Neonatal Intensive Care

R.3.14 Housekeeping

Figure R.15 shows the majority of respondents did not feel that housekeeping was particularly essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. The mode was four, the median was three, and the mean was 3.08. It is possible the 72-hour timeframe associated with the survey led some to believe that a loss of housekeeping for a fairly short period of time could be managed by other staff members.

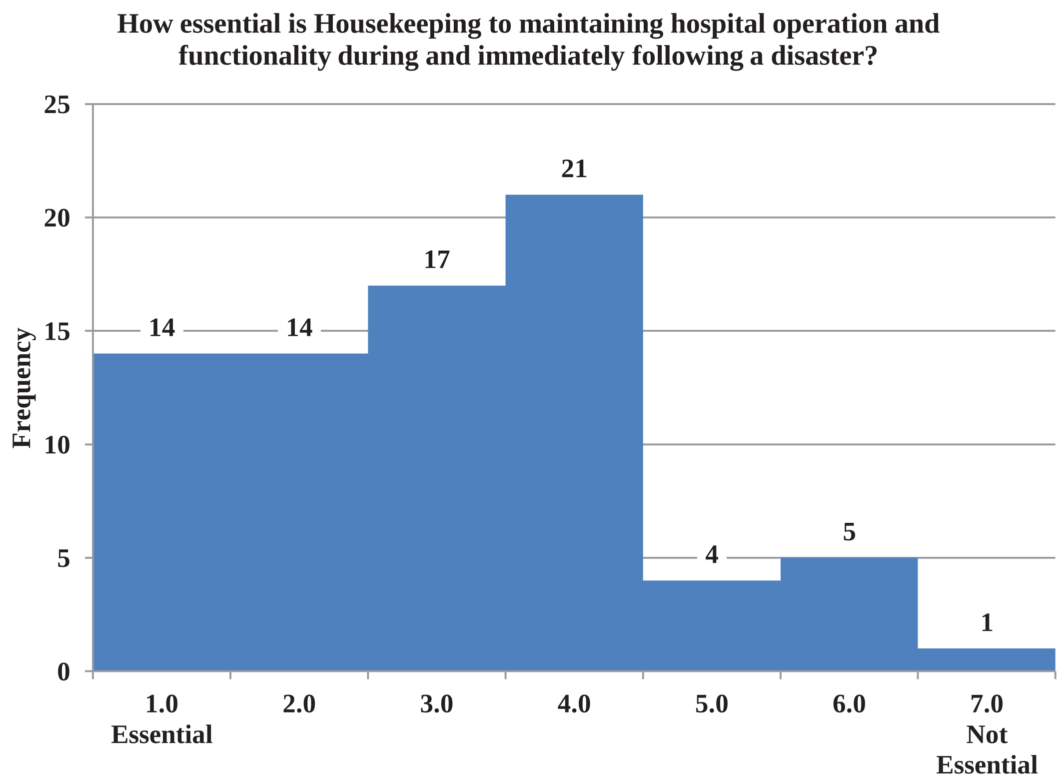

Figure R.15: Essentialness of Housekeeping

R.3.15 Medical Records

Figure R.16 shows a majority of respondents gave Medical Records a score of 1 to 3 when determining whether it is essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. However, a fairly large number of respondents gave it a score of 4 or greater. It is possible that many respondents were not concerned about the medical history of patients during a disaster or believed that new medical records could be generated and combined with existing records after the event.

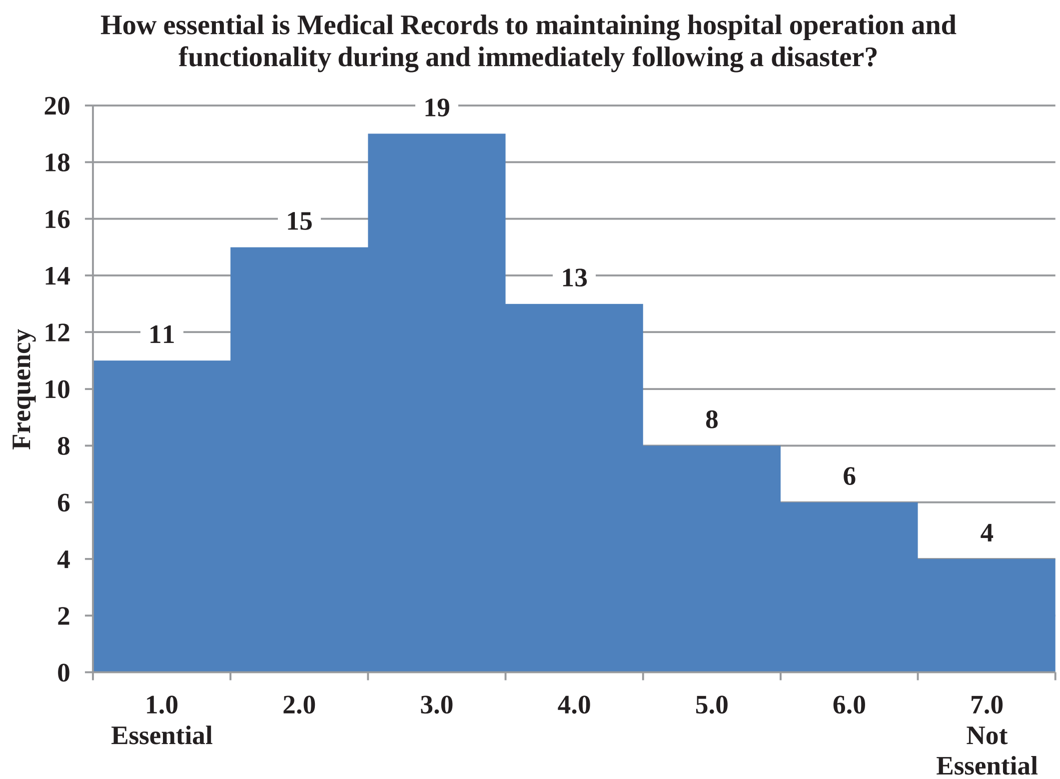

Figure R.16: Essentialness of Medical Records

R.3.16 Obstetrics / Gynecology

Figure R.17 shows a majority of respondents gave Obstetrics and Gynecology a score of 3 to 5 when determining whether they are essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. However, there were also 13 respondents who gave it a score of 1. I suspect that by combining a service related to labor and delivery with a service associated with primary and preventive care left some respondents uncertain about how to score the item. If they were separated into "labor and delivery" and "OB/GYN (primary and preventive)" the scores might be less variable.

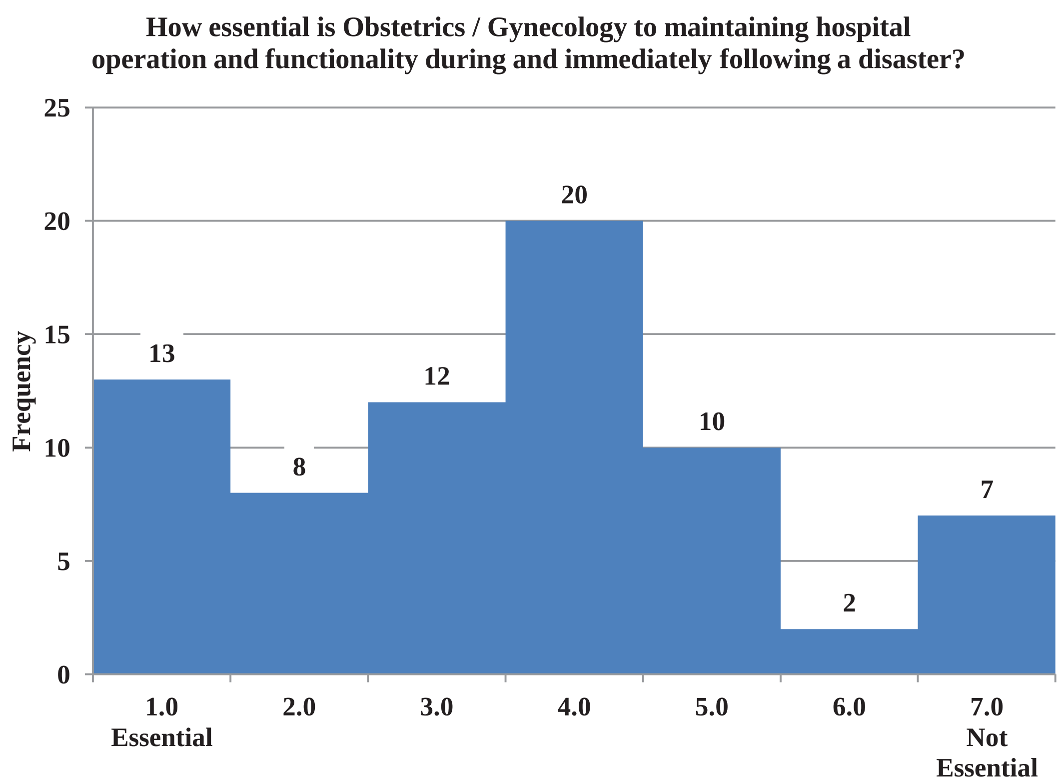

Figure R.17: Essentialness of Obstetrics and Gynecology

R.3.17 Laundry

Figure R.18 shows a majority of respondents gave laundry services a score of 2 to 4 when determining whether they are essential for maintaining hospital operations and functionality within the first 72-hours of a disaster event. However, 22 respondents gave them a score of 5 to 7. It is possible that many hospitals maintain stocks of linen and patient gowns on-hand, which could mean that a disruption would have to last for days before the impact is felt. It is also possible that many hospitals contract laundry services with outside vendors in which case they may not view it as a hospital function.

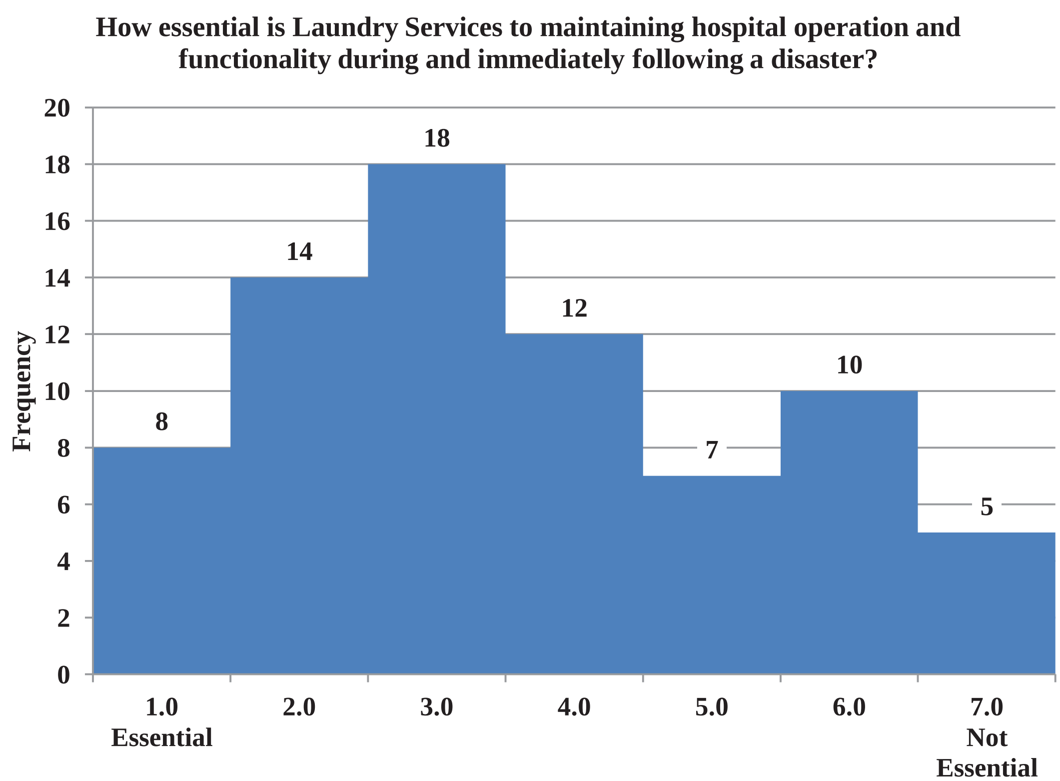

Figure R.18: Essentialness of Laundry

R.4 Conclusion

The hospital services that are deemed to be most important are those associated with emergency, surgical, and critical care. Those are followed by important diagnostic services like laboratory and radiology. Nursing care and pharmacy round out those services that have a mean essentialness score less than two. Of the remaining nine services, five are either support or administrative in nature. At first blush, this appears to belie the close and dependent relationship that exists between clinical, ancillary, support, and administrative services.

When the rankings are normalized, the findings from the Hospital Rehabilitation, Impediments, and Incentives Project are similar to those reported by PAHO (2000). The key differences are dietary (nutrition care) and laundry, which were deemed less essential in the hospital hazard mitigation project. Despite the frequency variability for some of the services, the mean score for all the services is less than four across the board. They are all leaning toward "essential." Unlike the prioritized view we might get if we consider how the services are ranked from one to 17, the mean scores indicate all of the services are recognized as being important to the continuity of hospital services.

What the list of 17 hospital services lacks are those functions that are not related to emergency or inpatient services. The PAHO list of functions includes several that are associated with primary and preventive care or rehabilitation. It is likely that if those types of services were included in the survey administered by the Hospital Rehabilitation, Impediments, and Incentives Project, the respondents would have rated at least some of them on the "not essential" end of the scale.

Appendix S

NONSTRUCTURAL SYSTEM QUANTITATIVE ANALYSIS

S.1 Introduction

The quantitative analysis of nonstructural systems evaluates how hospital staff members participating in the Hospital Rehabilitation, Impediments, and Incentives Project rated the importance of various building utility systems and building contents to hospital operations and functionality in the first 72-hours of a disaster. This appendix presents the system-level analysis of the hospital hazard mitigation project with descriptive statistics, histograms reflecting the frequency of the ratings, and an explanation of the findings.

S.2 System-level Analysis

This section addresses the system-level analysis performed on the data gathered by the Hospital Rehabilitation, Impediments, and Incentives Project. The respondents were asked to assign a value of one to seven, from "very important" to "not very important," to each of 13 hospital nonstructural systems based on the importance of those functions in maintaining hospital operations and functionality within 72-hours of a disaster. Table S.1 identifies the mean importance ratings for each of the systems.

Table S.1: Importance of Nonstructural Systems

Hospital Nonstructural Systems	Mean Importance
Electrical	1.31
Medical Gases	1.39
Lighting	1.67
Communications	1.71
Ventilation	1.79
Plumbing	1.95
Steam Sterilization	2.17
Fire Alarm	2.21
Refrigeration	2.25
Fire Sprinklers	2.26
Heating	3.05
Air Conditioning	3.34
Computers	3.43
Importance was measured on a 7-point scale where 1 was "very important" and 7 was "not very important."	

In addition, the participants identified, in order, the three systems they felt were most important. Figure S.1 shows that electrical, medical gases, and ventilation received the most first mentions with medical gases, electrical, and communications receiving the most total mentions.

The effects of an outage of some nonstructural systems will be felt immediately, while others may not be felt at all. The loss of electricity will have an immediate impact on the delivery of health care. However, the loss of the fire alarm or fire sprinkler, and the resulting increase in risk associated with a fire event, may go completely unnoticed by most staff members and patients.

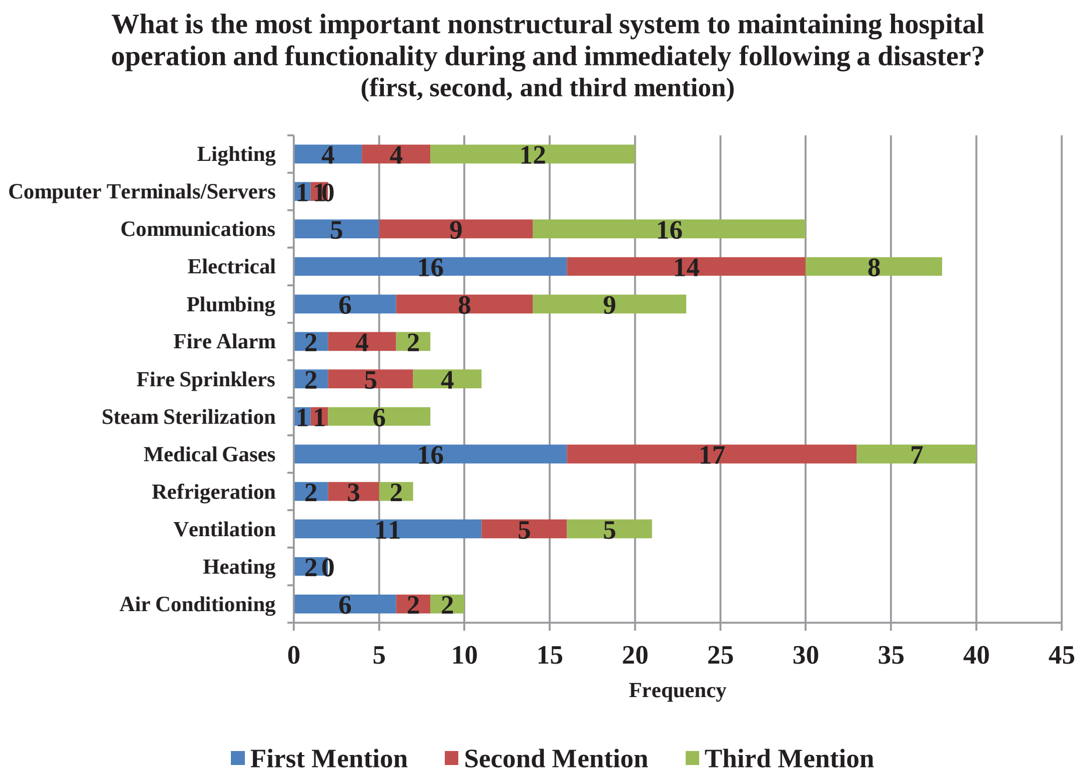

Figure S.1: Most Important Nonstructural Systems

S.2.1 Electrical

There is broad agreement among the respondents about the importance of the internal electrical system to maintaining hospital operation and functionality. Figure S.2 shows the electrical system was ranked "very important" by more respondents than any other nonstructural system. Sixty of 75 respondents gave it a rating of one, meaning they considered the system very important. Ten of 75 respondents rated it a two.

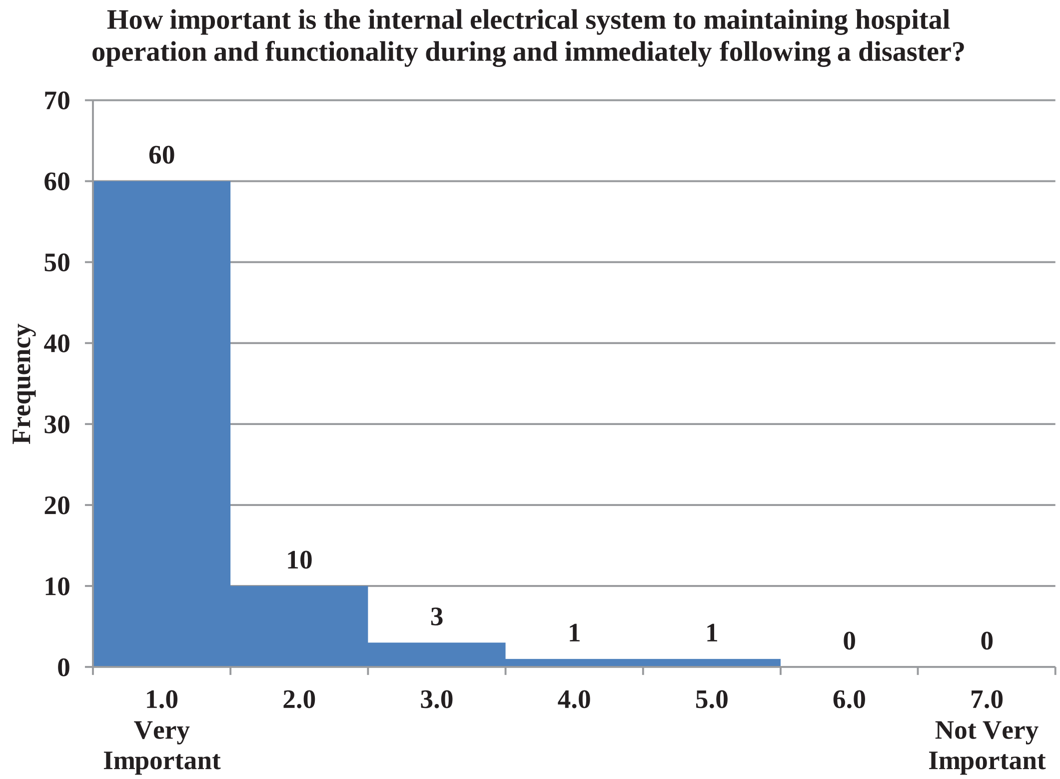

Figure S.2: Importance of the Hospital Electrical System

S.2.2 Medical Gases

Figure S.3 shows a majority of respondents ranked medical gases as very important for maintaining hospital operations and functionality during the 72-hours following a disaster. It received the second most "very important" responses after the internal electrical system. Medical gases are certainly an important resource in treatment. Additionally, medical air “powers” pneumatic medical and surgical instruments.

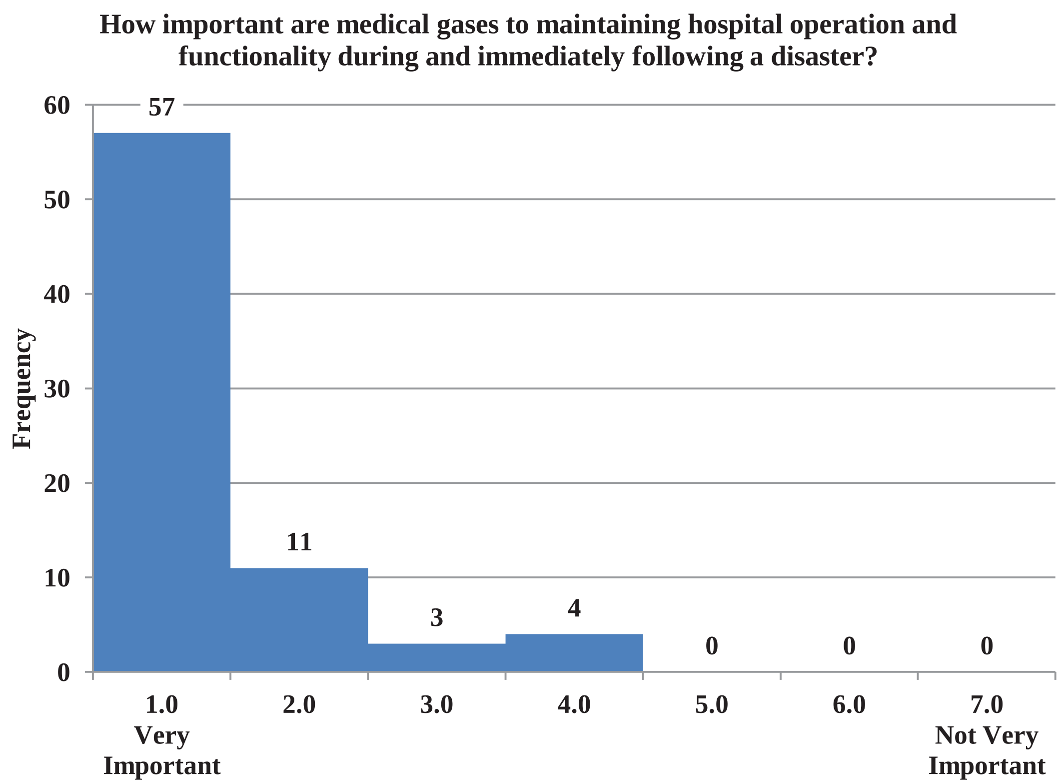

Figure S.3: Importance of Medical Gases

S.2.3 Lighting

Figure S.4 shows a majority of respondents considered lighting to be very important for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Although it is not clear from the terminology, I suspect this question was addressing interior lighting although it does not differentiate between general and task lighting. It is also possible that it intended to ask about both interior lighting and exterior lighting on the hospital campus.

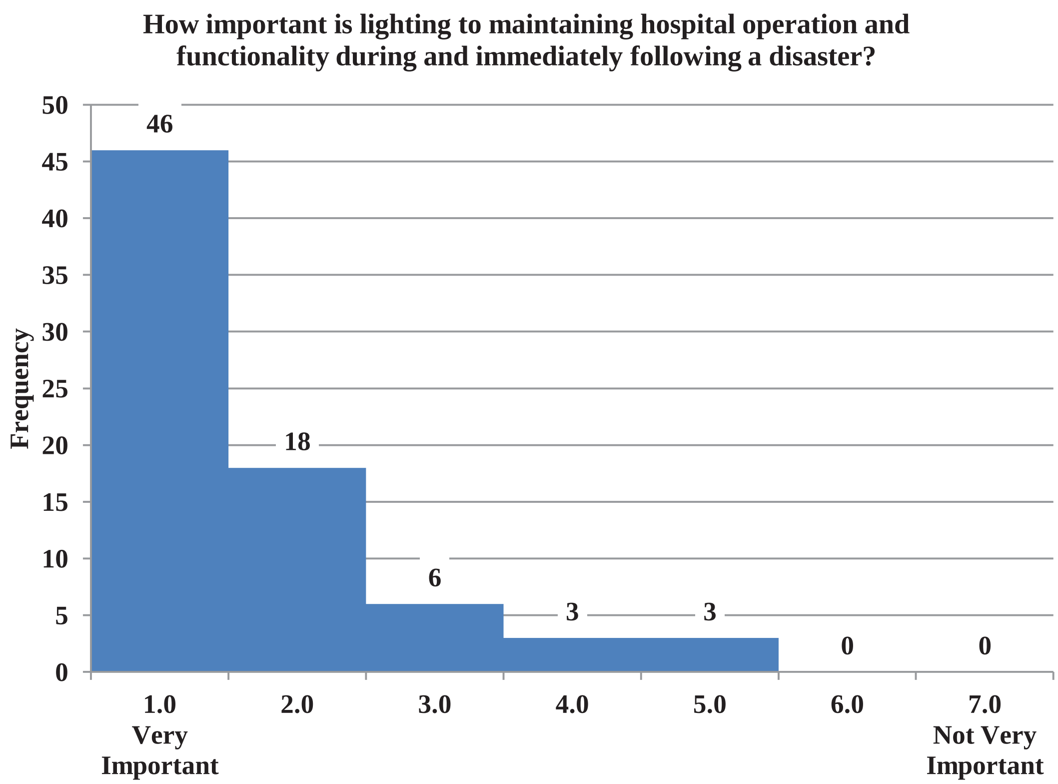

Figure S.4: Importance of Lighting

S.2.4 Communications

Figure S.5 shows a majority of respondents considered communications to be very important for maintaining hospital operations and functionality within the first 72-hours of a disaster event. The description for this item does not differentiate between different forms of internal communication, which may include telephones, radios, pagers, and email.

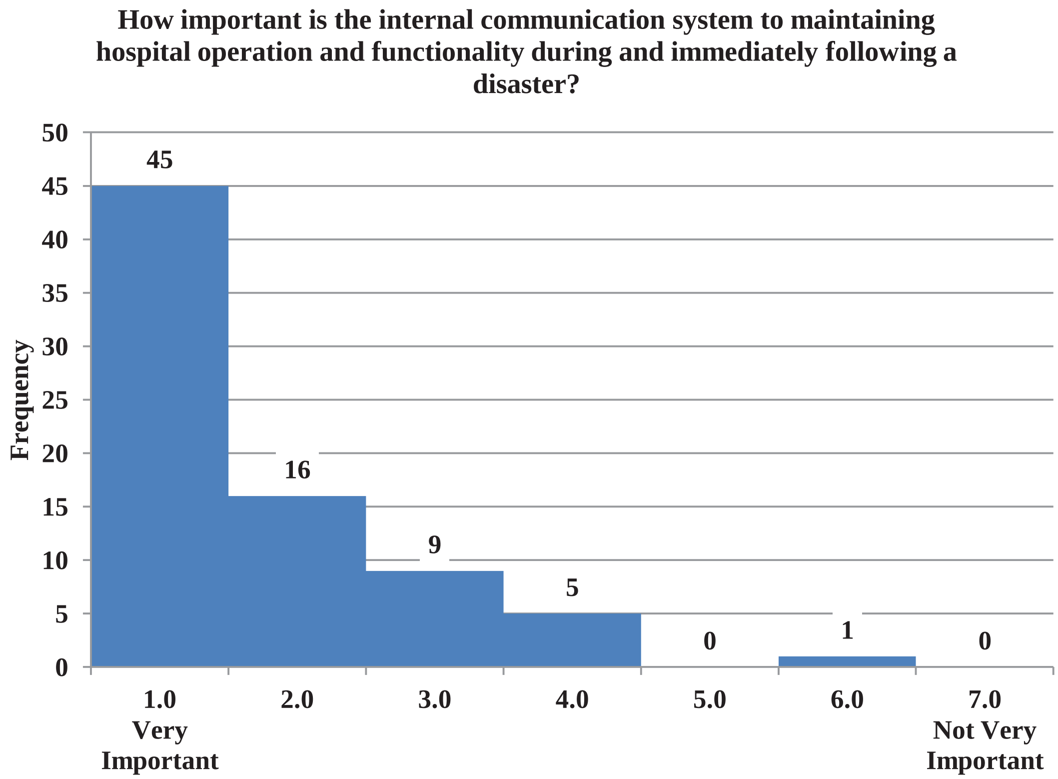

Figure S.5: Importance of the Internal Communications System

S.2.5 Ventilation

Figure S.6 shows a majority of respondents gave ventilation a rating of 1 or 2 when determining how important it is for maintaining hospital operations and functionality within the first 72-hours of a disaster event. This system is associated with movement of air rather than its heating, cooling, or conditioning (regulation of humidity, filtration, etc.). Ventilation is important for managing the number of air changes in a space, which is regulated within building codes.

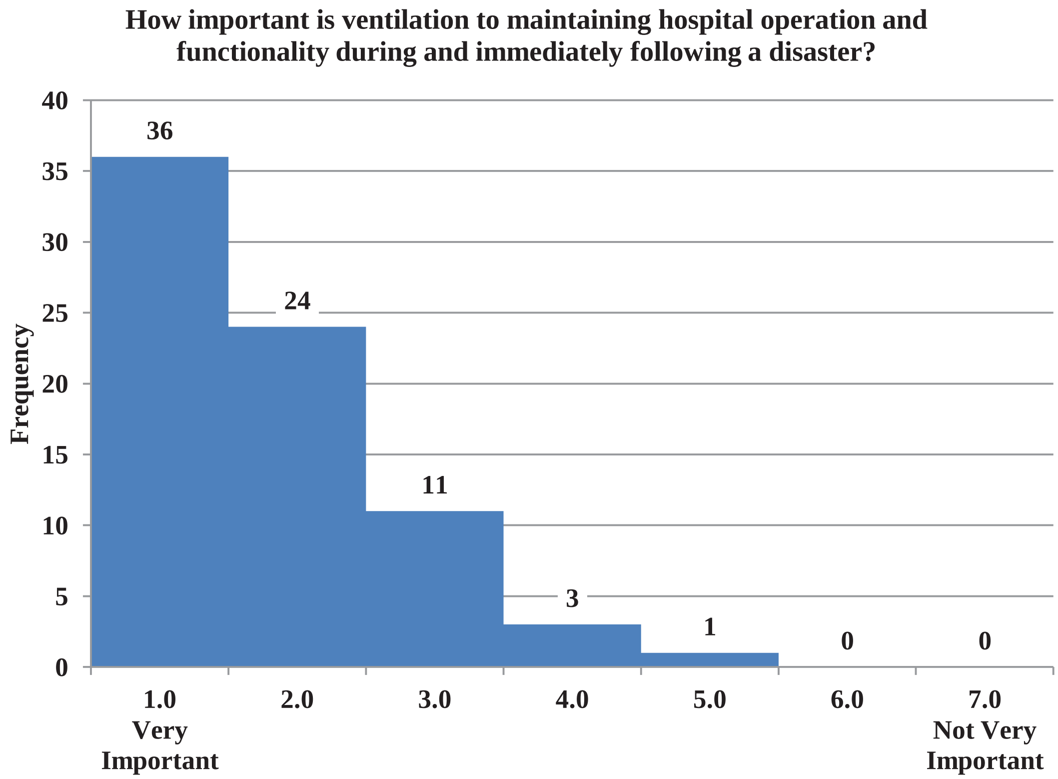

Figure S.6: Importance of Ventilation

S.2.6 Plumbing

Figure S.7 shows a large majority of respondents gave plumbing a rating of 1 to 3 when determining how important it is for maintaining hospital operations and functionality within the first 72-hours of a disaster event. It is not evident if respondents viewed plumbing as synonymous with water although water was not listed as a separate nonstructural system on the survey. Plumbing is the delivery device rather than the service. If water was more explicit in the survey, it may have received a higher importance rating.

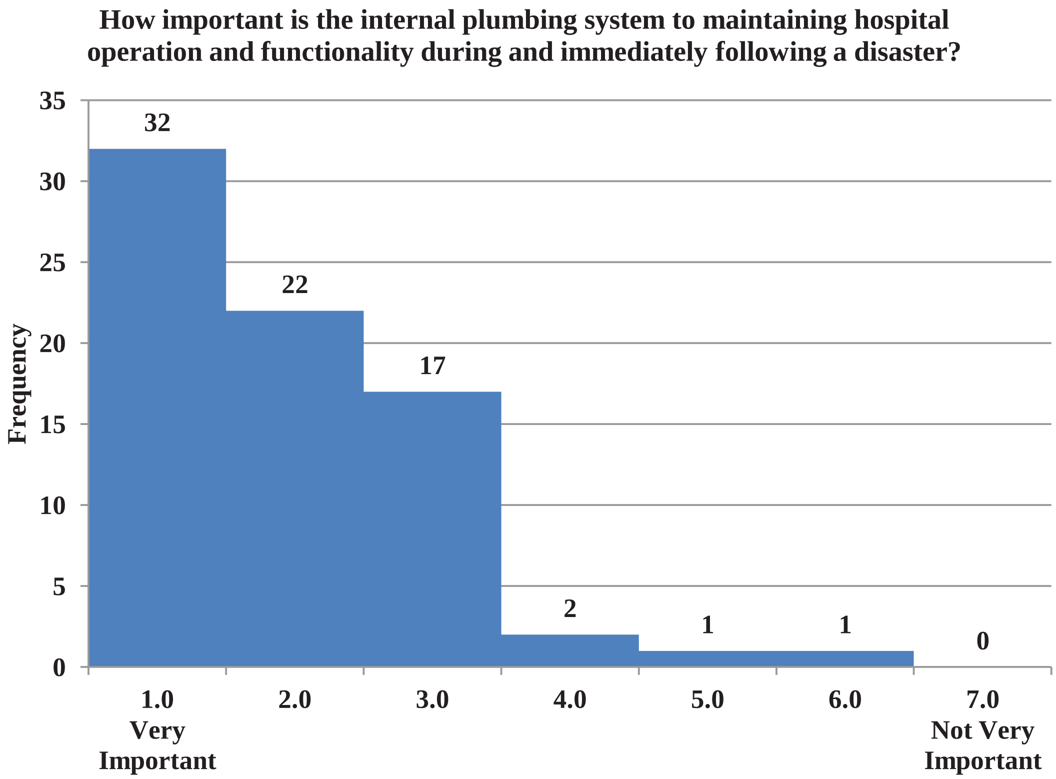

Figure S.7: Importance of the Internal Plumbing System

S.2.7 Steam Sterilization

Figure S.8 shows a majority of respondents gave steam sterilization a rating of 1 or 2 when determining how important it is for maintaining hospital operations and functionality within the first 72-hours of a disaster event. While steam sterilization is by far the most prevalent method of disinfecting instruments and supplies in hospitals, it is not the only one available to them. There are also chemical solutions in which items can be soaked for a period of time. Additionally, there are multiple ways of sterilizing equipment and supplies within a hospital. Bulk sterilization typically occurs in Central Material Service, but the surgical suites and some other treatment areas frequently have flash sterilizers to quickly clean instruments or small items in an emergency.

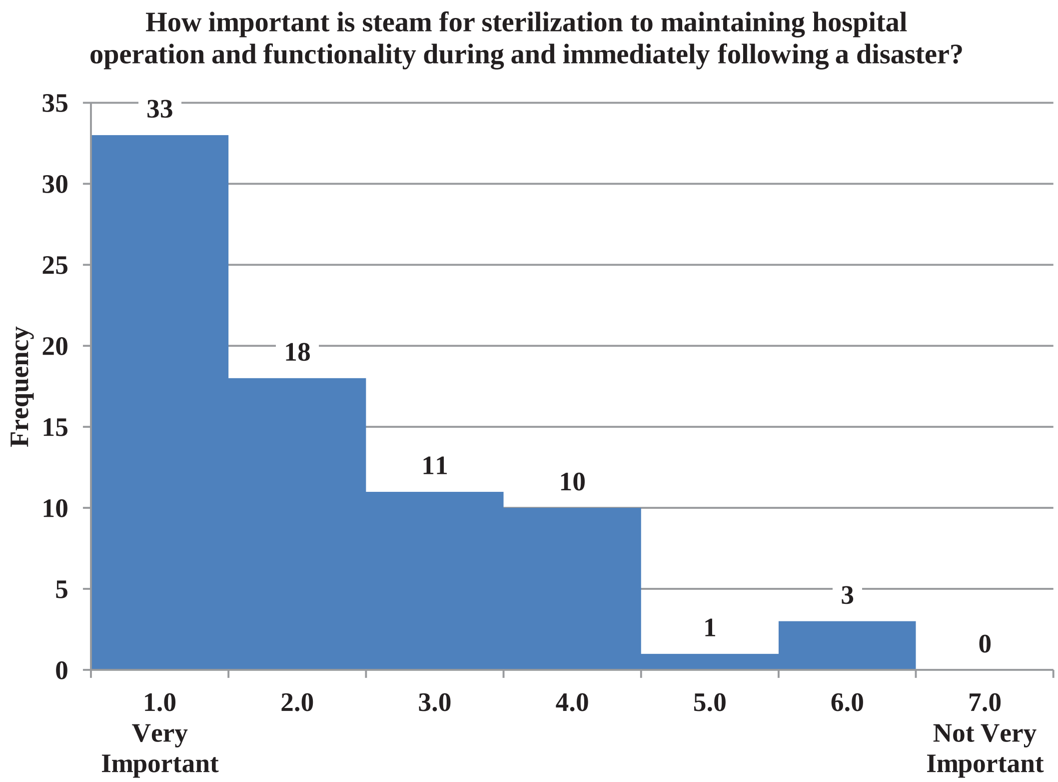

Figure S.8: Importance of Steam for Sterilization

S.2.8 Fire Alarm

Figure S.9 shows a majority of respondents gave the fire alarm a rating of 1 or 2 when determining how important it is for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Hospitals that are accredited by The Joint Commission conduct fire drills once per shift, per quarter, per building. This means that hospital staff members are well acquainted with the fire alarm system and its purpose. While the loss of the fire alarm system may go unnoticed by most staff members, they all understand its role in alerting them to this particular threat.

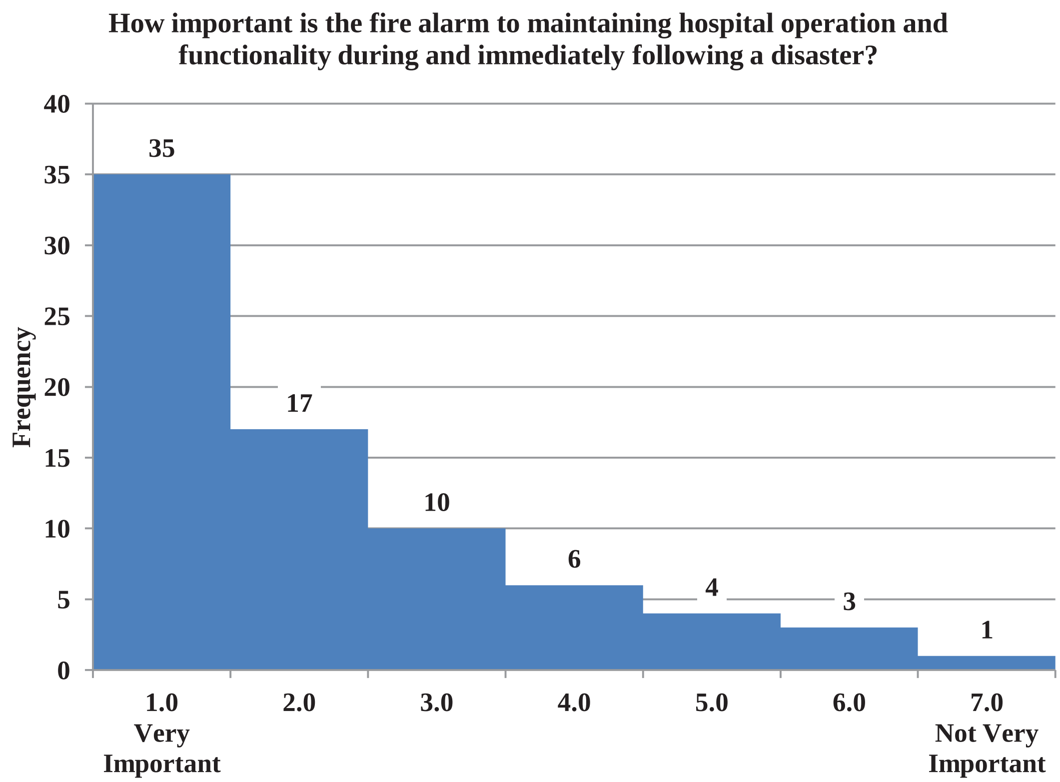

Figure S.9: Importance of the Fire Alarm System

S.2.9 Refrigeration

Figure S.10 shows a majority of respondents gave refrigeration a rating of 1 or 2 when determining how important it is for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Many items in hospitals need to be refrigerated, including some medications, blood, specimens for laboratory analysis, and food. Additionally, some items need to be frozen, which is not necessarily covered under the heading, "refrigeration."

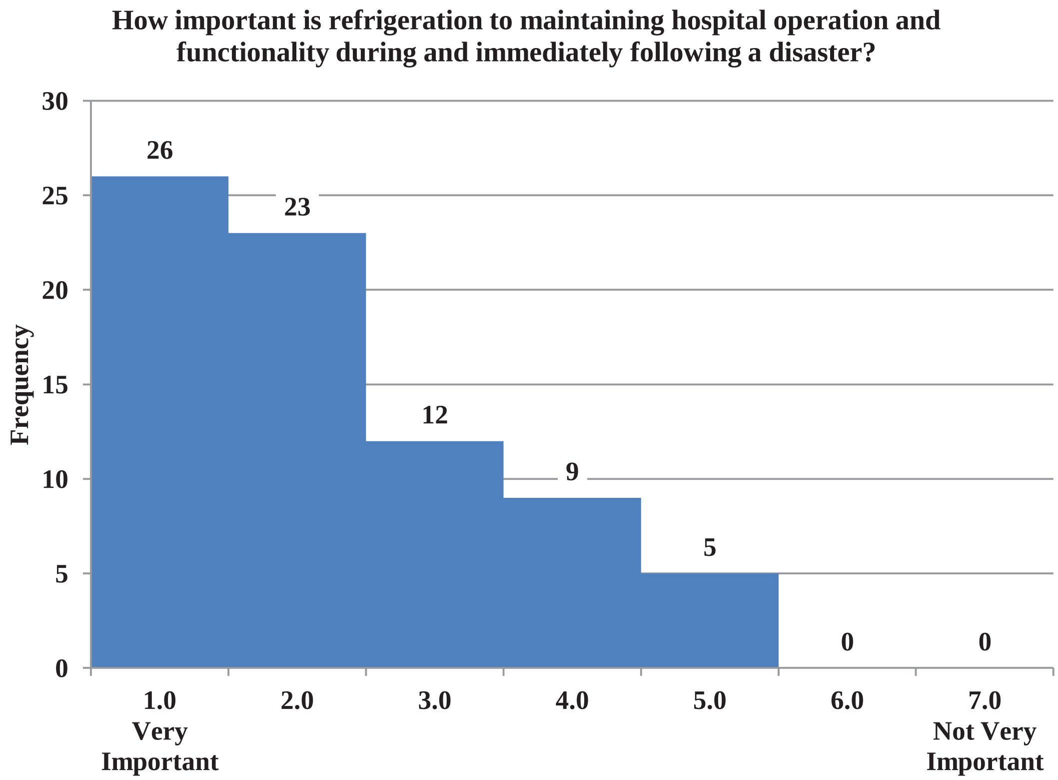

Figure S.10: Importance of Refrigeration

S.2.10 Fire Sprinklers

Figure S.11 shows a majority of respondents gave fire sprinklers and piping a rating of 1 or 2 when determining how important they are for maintaining hospital operations and functionality within the first 72-hours of a disaster event. However, like the fire alarm, it is likely that many hospital occupants would be unaware of a disruption in the fire sprinkler system.

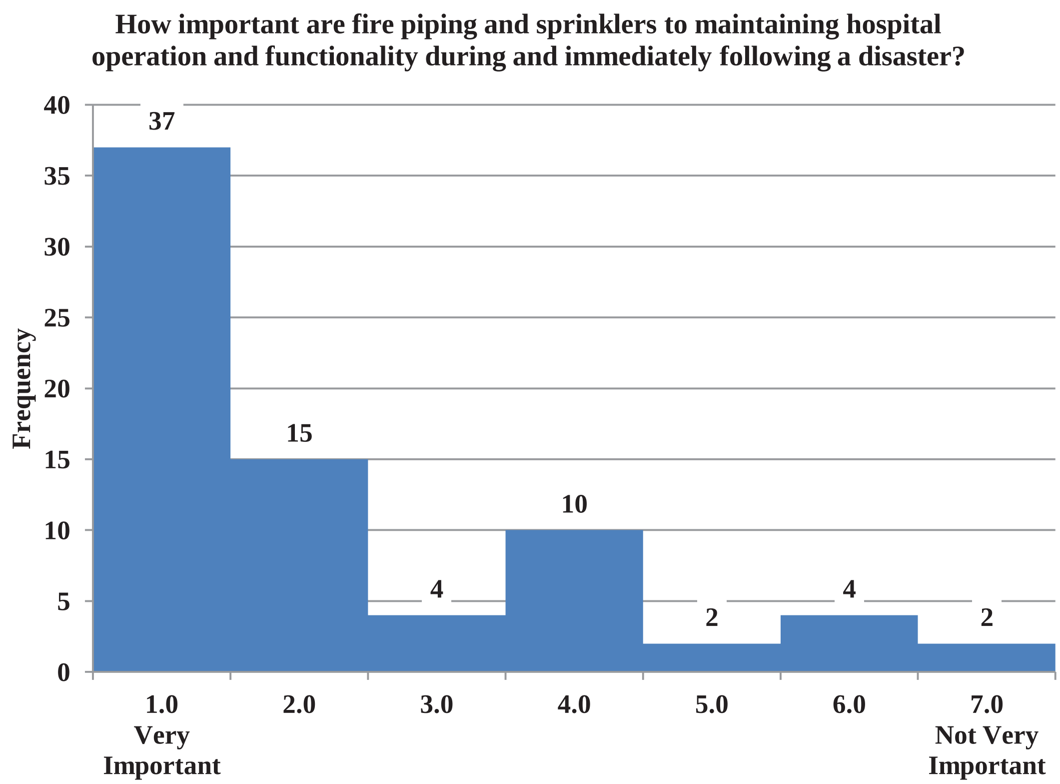

Figure S.11: Importance of Fire Piping and Sprinklers

S.2.11 Heating

Figure S.12 shows a majority of respondents gave heating a rating of 2 to 4 when determining how important it is for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Given modern building codes and the thermal protection built into many large buildings, the loss of the heating system may not drastically affect internal temperatures for a day or more. Geography may play a part in the responses as well. The three states in which interviews were conducted have different climates.

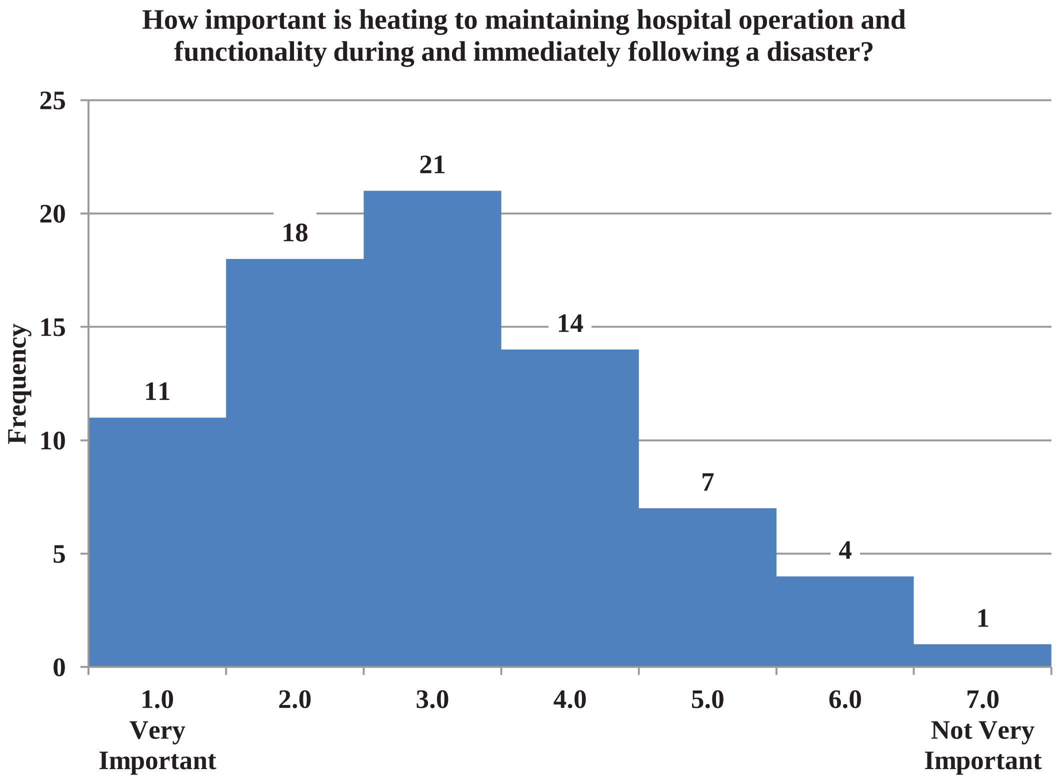

Figure S.12: Importance of Heating

Perhaps unsurprisingly, Figure S.13 reflects that respondents from New York were more likely to indicate that heat was very important or important followed by informants from Tennessee and California, respectively.

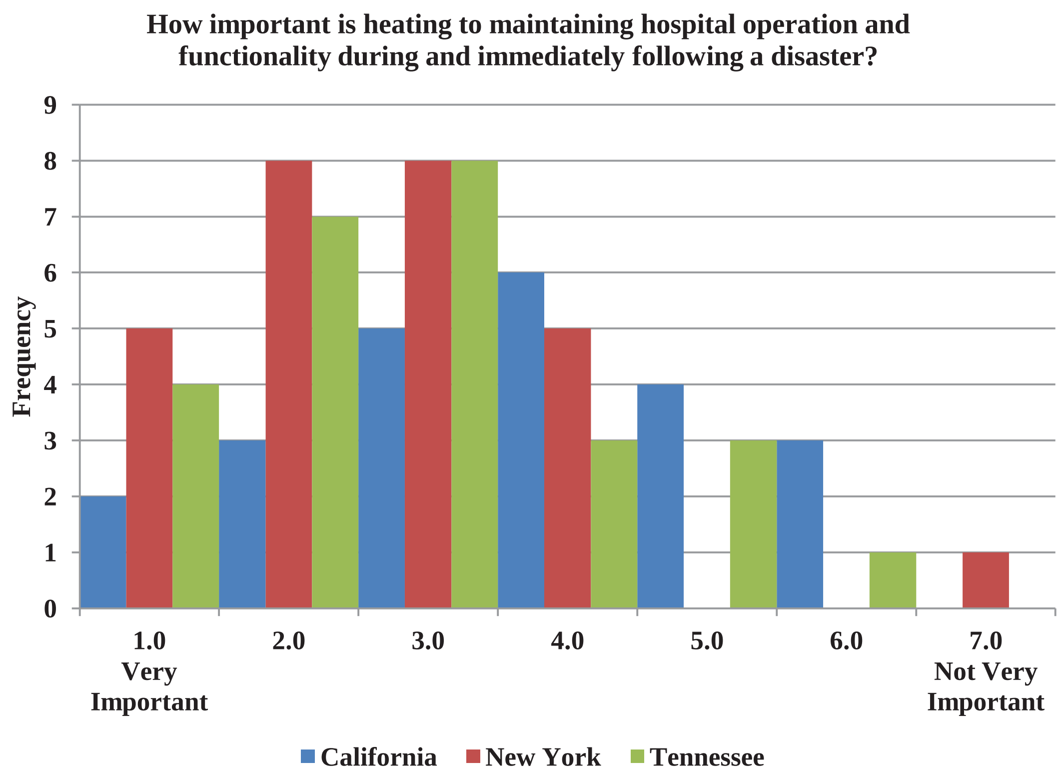

Figure S.13: Importance of Heating by Hospital Location

S.2.12 Air Conditioning

Figure S.14 shows a majority of respondents gave air conditioning a rating of 2 to 4 when determining how important it is for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Air conditioning is necessary for both cooling the air and controlling the level of humidity. Like heating, geography and climate probably play a role in how respondents rate its importance.

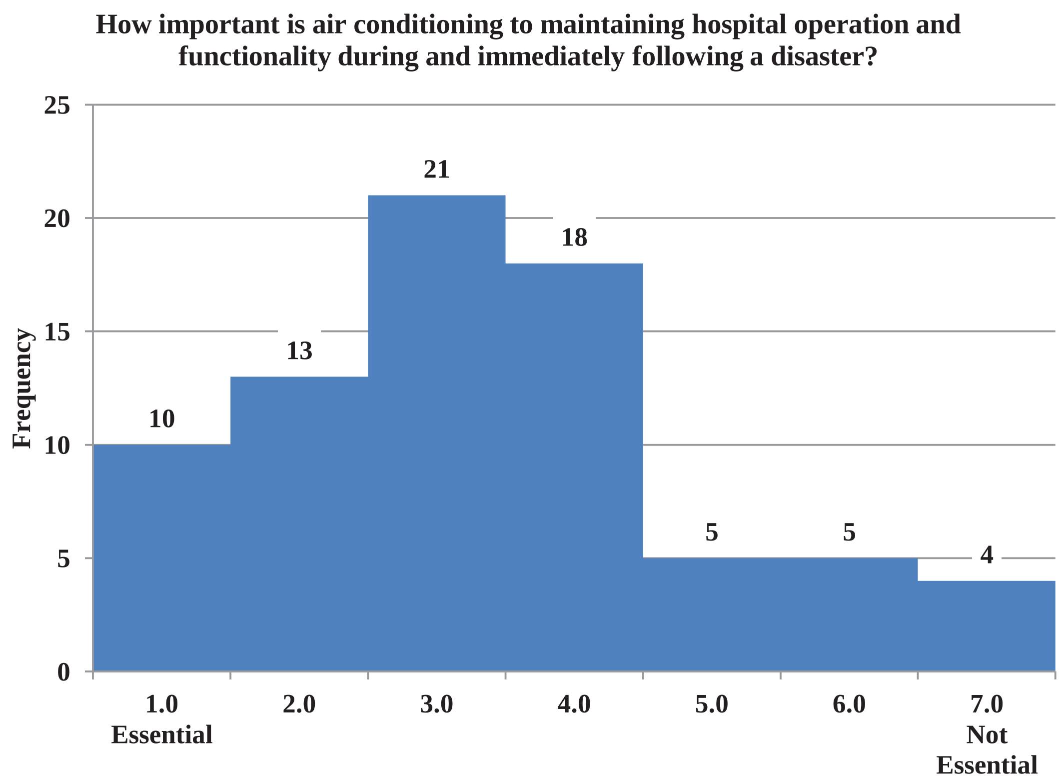

Figure S.14: Importance of Air Conditioning

Figure S.15 shows that respondents from Tennessee were more likely to rate air conditioning a one or two than informants from the other two states. This may be related to both summer temperatures and relative humidity.

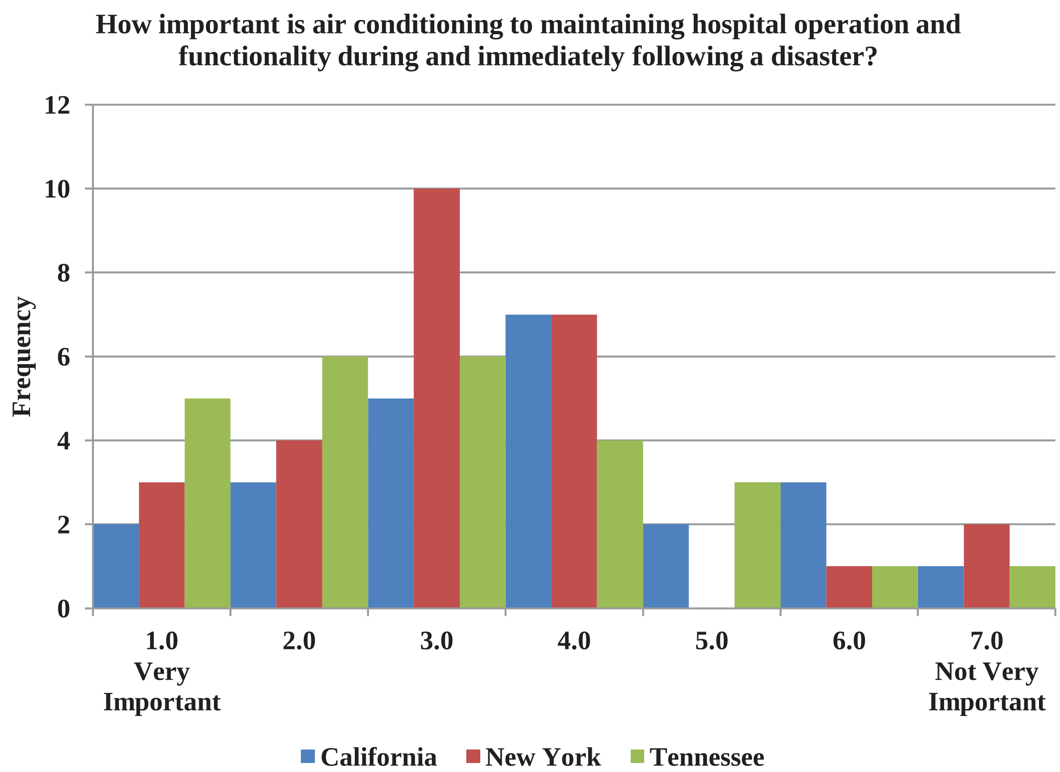

Figure S.15: Importance of Air Conditioning by Hospital Location

S.2.13 Computers

Figure S.16 shows a majority of respondents gave computers a rating of 2 to 4 when determining how important they are for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Computer terminals and servers were ranked similarly to air conditioning and heating. Because the research was conducted in 2000 and 2001, it is possible computers had not gained widespread use within the hospitals beyond email and administrative tasks. Today, with the proliferation of electronic medical records, health information management systems, and automated inventory management, it is possible computers terminals and servers would be deemed more important.

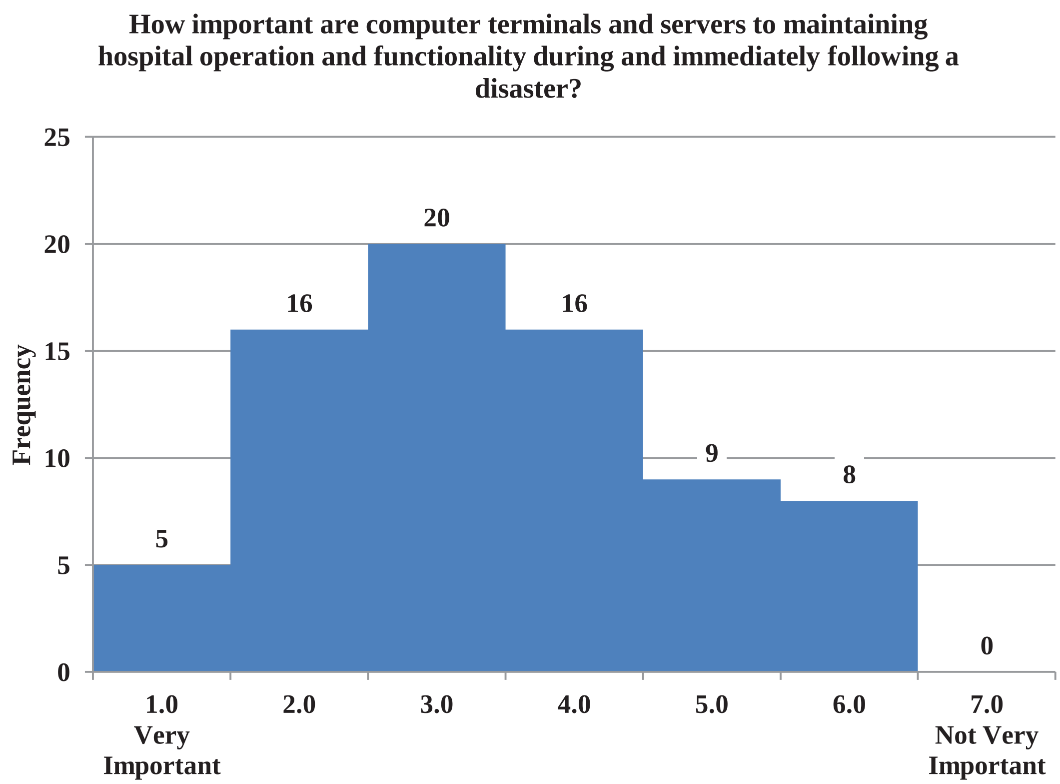

Figure S.16: Importance of Computers and Servers

S.3 Conclusion

Four of the systems, electrical, medical gases, lighting, and communications, had median and mode rankings of one. They were clearly deemed the most important among the 13 nonstructural systems. Interestingly, plumbing, which I consider to be synonymous with water, had a mean of 1.95 and median of two. I expected its importance to be closer to that of electricity. It is possible the focus on the means of conveyance rather than the service affected the ratings. Regardless, all of the systems had a mean rating less than 3.5, which indicates they were all viewed as important.

Appendix T

EXTERNAL LIFELINES QUANTITATIVE ANALYSIS

T.1 Introduction

The quantitative analysis of lifelines evaluates how hospital staff members who participated in the Hospital Rehabilitation, Impediments, and Incentives Project rated the importance of various external support systems to hospital operations and functionality in the first 72-hours of a disaster. This appendix presents the system-level analysis of the hospital hazard mitigation project with descriptive statistics, histograms reflecting the frequency of the ratings, and an explanation of the findings.

T.2 System-level Analysis

This section addresses the system-level analysis performed on the data gathered by the Hospital Rehabilitation, Impediments, and Incentives Project. The respondents were asked to assign a value of one to seven, from “very important” to “not very important” to each of seven external lifelines based on the importance of those functions in maintaining hospital operations and functionality within 72-hours of a disaster. Table T.1 identifies the mean importance ratings for each of the systems.

Table T.1: Importance of External Lifelines

Hospital Rehabilitation, Impediments, and Incentives Project	Mean Importance
Water	1.40
Electrical	1.64
Telephone	2.08

Table T.1 continued

Transportation	2.14
Sewage	2.16
Natural Gas	2.78
Data Communications	3.28
Importance was measured on a 7-point scale where 1 was “important” and 7 was “not important.”	

In addition, the participants identified, in order, the three systems they felt were most important. Figure T.1 shows that electrical, transportation, and water received the most first mentions and the most total mentions. Much like nonstructural systems, the effects of disruptions to some lifelines will be felt more immediately than others. It will also be easier to find alternate means of service delivery for some lifelines than for others.

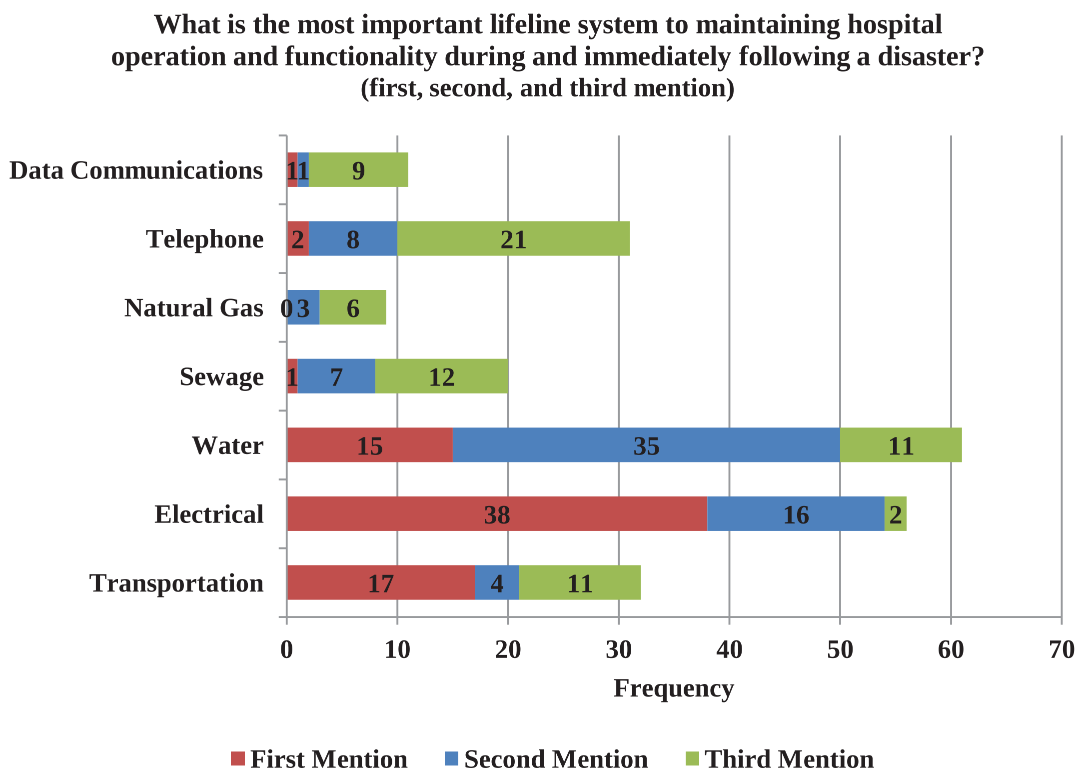

Figure T.1: Most Important Lifelines

T.2.1 Water

Figure T.2 shows that a large majority of respondents considered the water lifeline to be very important for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Water is necessary for the proper delivery of patient care in many ways. Hand washing, personal hygiene, flushing toilets, personal hydration, food preparation, steam sterilization, many large air conditioning systems, and steam heat are all dependent on the provision of water.

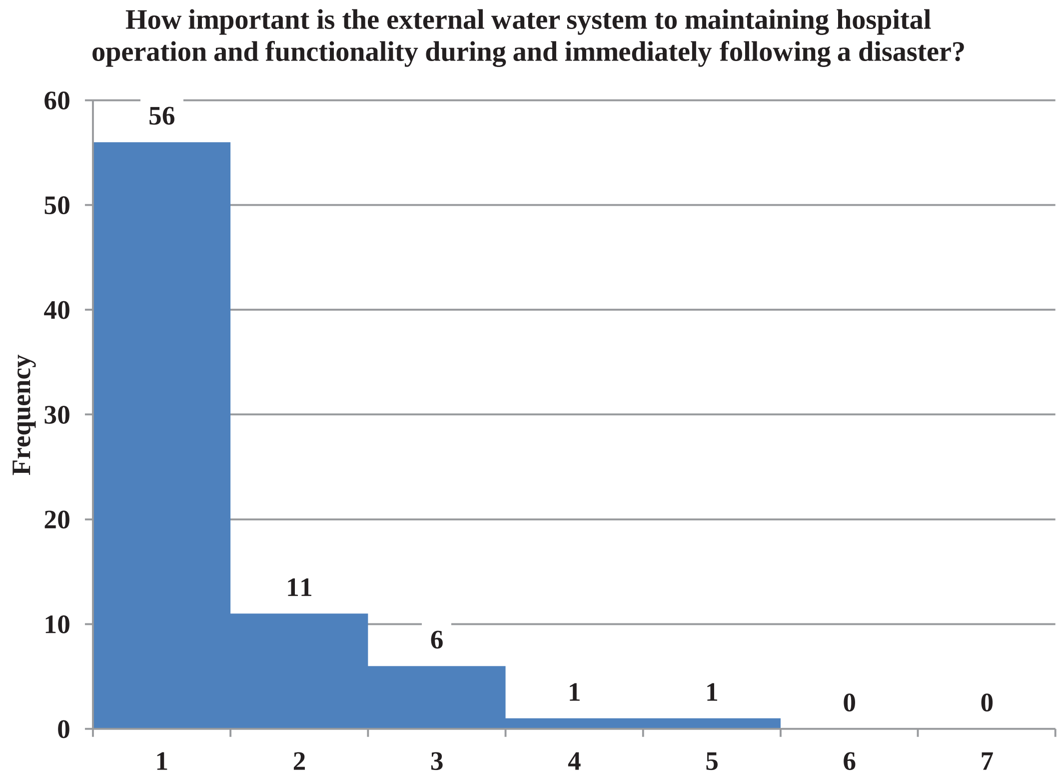

Figure T.2: Importance of the Water Lifeline

T.2.2 Electrical

Figure T.3 shows that a large majority of respondents considered the electrical lifeline to be very important for maintaining hospital operations and functionality within the first 72-hours of a disaster event. While hospitals in the United States are required to have emergency generators, the loss of the electrical lifeline is a significant event for any medical treatment facility.

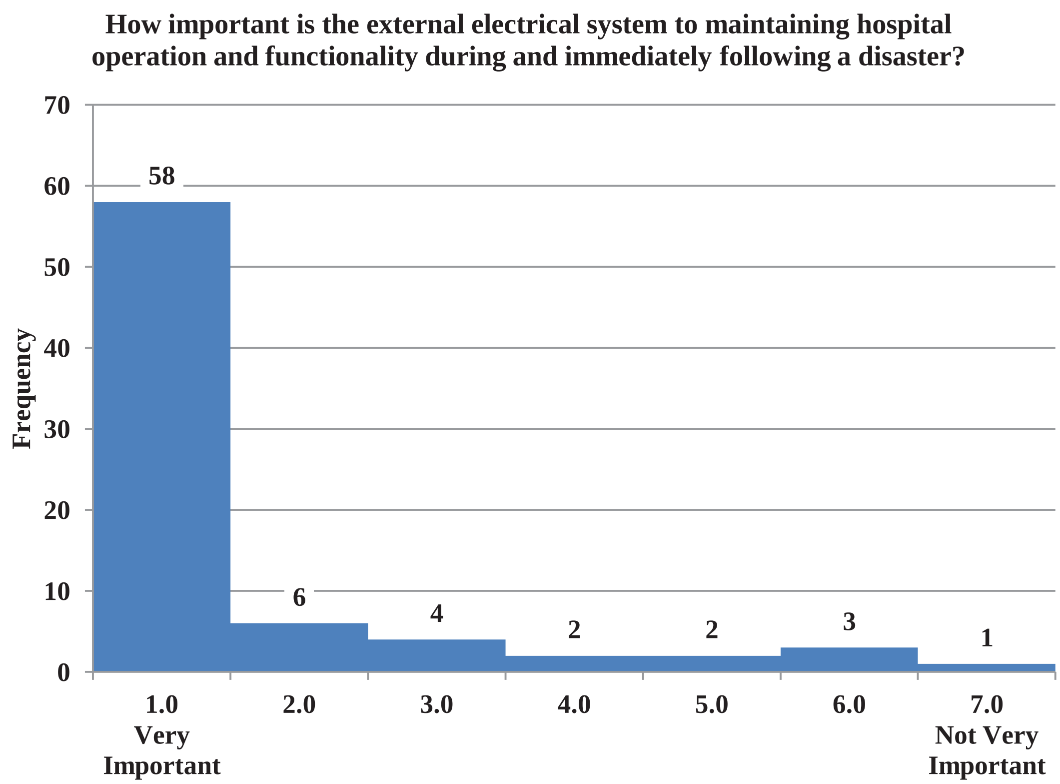

Figure T.3: Importance of the Electrical Lifeline

T.2.3 Telephone

Figure T.4 shows that a majority of respondents rated external telephone service a one or two when considering its importance for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Because this data was gathered in 2000 and 2001, the prevalence of mobile telephones was lower than it is today. Were the survey administered again, it might be amended to include mobile telephone service, too.

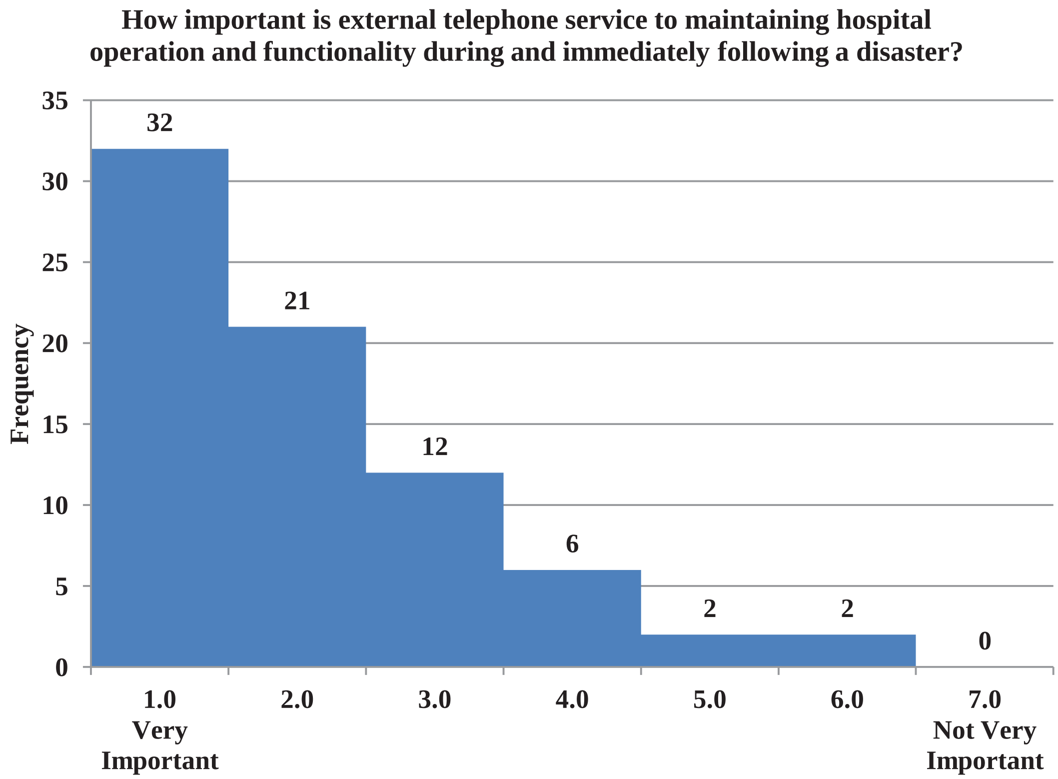

Figure T.4: Importance of External Telephone Service

T.2.4 Transportation

Figure T.5 shows a majority of respondents gave transportation a rating of one or two when determining how important it is for maintaining hospital operations and functionality within the first 72-hours of a disaster event. The network is important for enabling access for patients and staff.

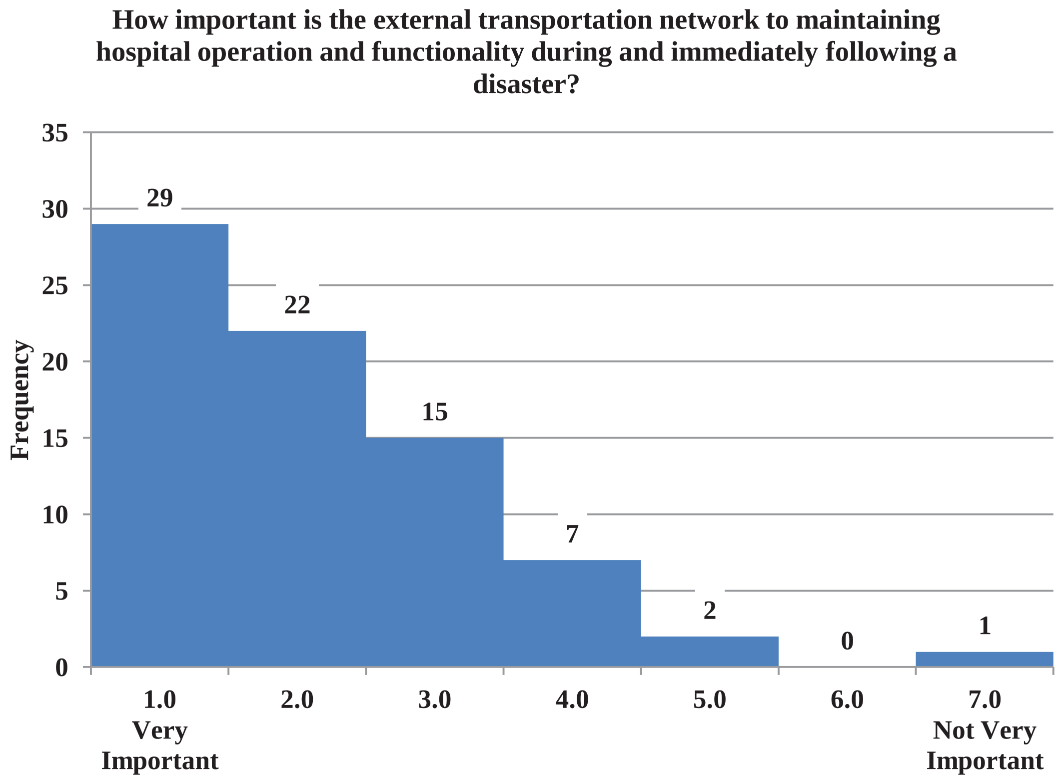

Figure T.5: Importance of the Transportation Network

T.2.5 Sewage

Figure T.6 shows a majority of respondents gave sewage a rating of one or two when determining how important it is for maintaining hospital operations and functionality within the first 72-hours of a disaster event. The sanitary sewer is necessary for carrying away waste, including waste water from hand washing, toilet activities, sterilization, and food preparation. However, some of these may be bagged as biomedical waste during emergencies, and, if portable toilets are provided, the demand on the sanitary sewer system will be significantly reduced.

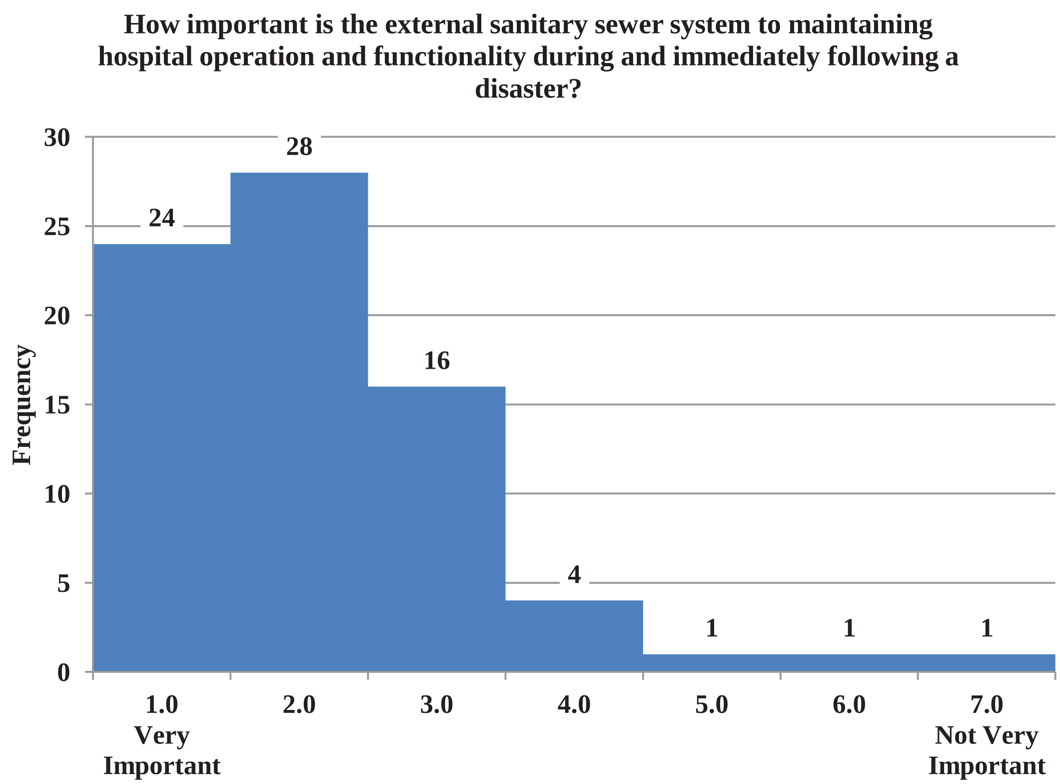

Figure T.6: Importance of the Sanitary Sewer Lifeline

T.2.6 Natural Gas

Figure T.7 shows a majority of respondents gave natural gas a rating of one to three when determining how important it is for maintaining hospital operations and functionality within the first 72-hours of a disaster event. In hospitals, natural gas is commonly used for cooking and to heat occupied spaces and water. Its mean rating was slightly better than that of hospital heating, but it had many more ratings of one.

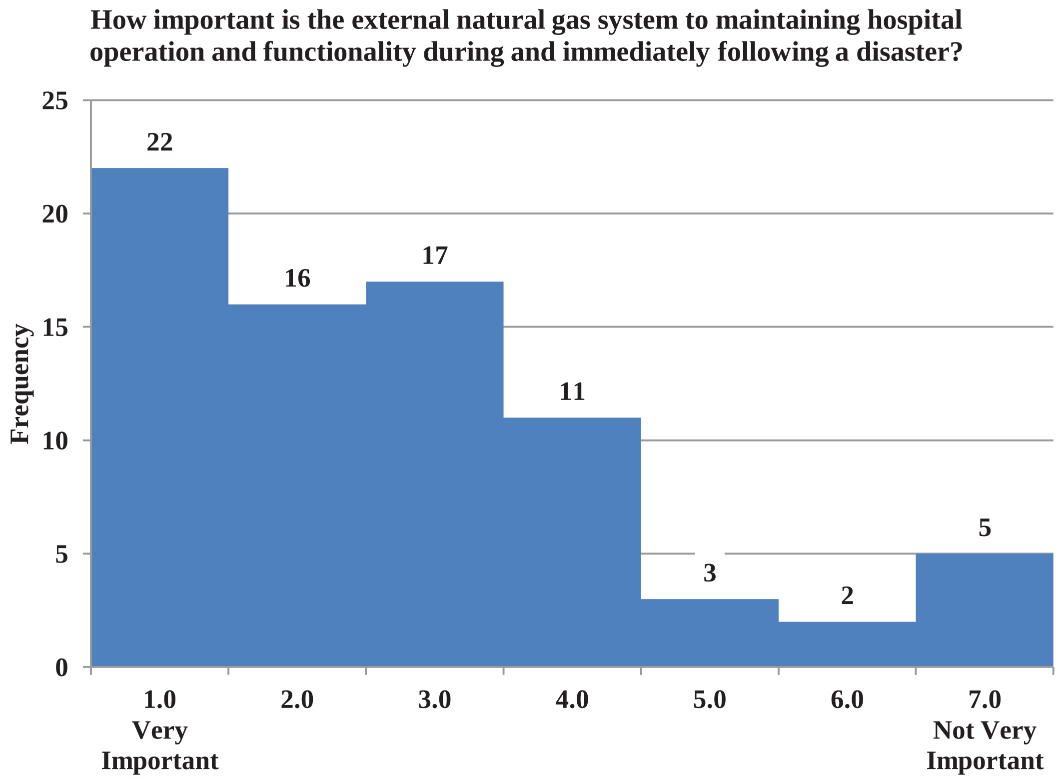

Figure T.7: Importance of the Natural Gas Lifeline

T.2.7 Data Communications

Figure T.8 shows a majority of respondents gave data communications a rating of one to three when determining how important it is for maintaining hospital operations and functionality within the first 72-hours of a disaster event. Its rating was roughly equivalent to the rating that computer terminals and servers received on the nonstructural system survey. With the increased reliance on computers and data communications for electronic medical records, telemedicine, Internet access, and email, I suspect data communications would be considered more important if the survey were administered today.

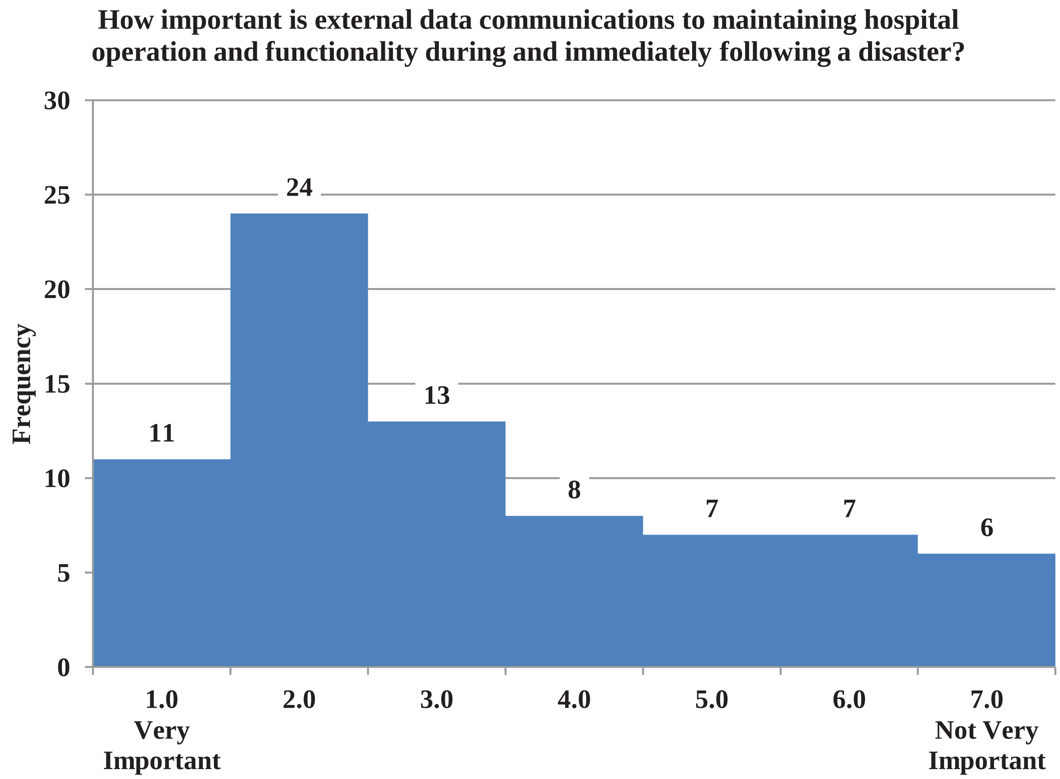

Figure T.8: Importance of the Data Communications Lifeline

T.3 Conclusion

The water and electrical lifelines were rated the most important among the seven systems evaluated. The respondents' rating of the water lifeline was more in keeping with how I expected the hospital plumbing system to be rated. The mean ratings for the other systems were all less than 3.5, which indicate they were all viewed as important.

Appendix U

TABLE OF OBJECTIVES

This appendix contains the objectives for the systems, subsystems, and components included in the influence diagram. Due to formatting limitations, the table of objectives is broken down into four separate tables in this appendix. The identification number for each item is common in all four tables, which should make navigating them easier. Table U.1 shows the descriptive name for each item, the type of objective it is (i.e., strategic, fundamental, or means), and the system association of the descriptive name.

Table U.1: Table of Objectives

ID	NAME	OBJECTIVE	SYSTEMS
1.0	Hospital Support to Community Disaster Response	Strategic	Community
2.0	Functional Hospital	Fundamental	Hospital Services; Personnel; Structural Systems; Nonstructural Systems
3.0	Hospital Services	Means	Hospital Services
3.1	Treatment Services	Means	Hospital Services
3.2	Ancillary Services	Means	Hospital Services
3.3	Support Services	Means	Hospital Services
3.3.1	Medical Logistics	Means	Hospital Services
3.3.2	Medical Transportation	Means	Hospital Services
3.4	Administrative Services	Means	Hospital Services
4.0	Hospital Staff	Means	Personnel
5.0	Structural Systems	Means	Structural
6.0	Nonstructural Systems	Means	Nonstructural
6.1	Architectural Elements	Means	Nonstructural
6.2	Building Utility Systems	Means	Nonstructural
6.2.1	Electrical	Means	Nonstructural

Table U.1 continued

6.2.2	Water	Means	Nonstructural
6.2.3	Natural Gas	Means	Nonstructural
6.2.4	Steam	Means	Nonstructural
6.2.5	Sanitary Drainage	Means	Nonstructural
6.2.6	Storm Drainage	Means	Nonstructural
6.2.7	Heating, Ventilation, and Air Conditioning (HVAC)	Means	Nonstructural
6.2.8	Medical Gas	Means	Nonstructural
6.2.9	Medical Air	Means	Nonstructural
6.2.10	Central Vacuum	Means	Nonstructural
6.2.11	Mass Notification	Means	Nonstructural
6.2.12	Security	Means	Nonstructural
6.2.13	Communications	Means	Nonstructural
6.2.14	Fire Detection and Alarm	Means	Nonstructural
6.2.15	Fire Suppression	Means	Nonstructural
6.2.16	Elevator (Cable / Electric / Traction)	Means	Nonstructural
6.2.17	Elevator (Hydraulic)	Means	Nonstructural
6.3	Building Contents	Means	Nonstructural
7.0	Lifelines	Means	Lifeline
7.1	Electrical	Means	Lifeline
7.2	Water	Means	Lifeline
7.3	Natural Gas	Means	Lifeline
7.4	Steam	Means	Lifeline
7.5	Sanitary Sewer	Means	Lifeline
7.6	Storm Sewer	Means	Lifeline
7.7	Communications	Means	Lifeline
7.8	Solid Waste Collection	Means	Lifeline
8.0	Supply Chain	Means	Supply Chain
9.0	Transportation	Means	Transportation
10.0	Community Services	Means	Community Services
10.1	Fire Protection	Means	Community Services
10.2	Law Enforcement	Means	Community Services
10.3	Child Care	Means	Community Services

Table U.2 identifies the systems and their associated subsystems and components.

Table U.2: Systems, Subsystems, and Components

ID	SYSTEMS	SUBSYSTEMS	COMPONENTS
1.0	Community		
2.0	Hospital Services; Personnel; Structural Systems; Nonstructural Systems		
3.0	Hospital Services	Treatment Services; Ancillary Services; Support Services; Administrative Services	
3.1	Hospital Services	Treatment Services	Emergency; Surgery; Medical; Psychiatric
3.2	Hospital Services	Ancillary Services	Diagnostic (Laboratory, Radiology, Audiology); Therapeutic (Pharmacy, Physical Therapy, Occupational Therapy); Custodial (Assisted Living, Skilled Nursing)
3.3	Hospital Services	Support Services	Dining; Social Work; Religious Services; Medical Equipment Management; Facility Management; Medical Logistics; Medical Transportation; Sterilization; Housekeeping
3.3.1	Hospital Services	Support Services (Medical Logistics)	Medical Gas; Hospital Linen; Food; Medical Equipment; Pharmaceuticals; Medical Supplies; Hazardous Materials; General Waste Removal; Medical Waste Removal; Fuel
3.3.2	Hospital Services	Support Services (Medical Transportation)	Ground Vehicles; Rotary Wing; Fixed Wing
3.4	Hospital Services	Administrative Services	Admissions; Records; Discharge; Healthcare Administration; Human Resources; Resource Management; Safety; Patient Advocate; Infection Control; Patient Safety; Quality Management
4.0	Personnel	Clinical Staff; Ancillary Staff; Support Staff; Administrative Staff	
5.0	Structural		Foundation; Columns; Load Bearing Walls; Shear Walls; Floors; Roof

Table U.2 continued

6.0	Nonstructural	Architectural Elements; Building Utility Systems; Building Contents	
6.1	Nonstructural	Architectural Elements	Windows; Shutters; Doors; Wall Partitions; Ceilings; Lighting; Exterior Panels and Veneer; Parapets; Curtain Walls
6.2	Nonstructural	Building Utility Systems	Electrical; Water; Natural Gas; Sanitary Sewer; Storm Sewer; HVAC; Medical Gas; Central Vacuum; Mass Notification; Security; Telecommunications; Fire System; Conveying Systems
6.2.1	Nonstructural	Building Utility Systems (Electrical)	Service Entrance Equipment (Transformers, Switch/Service Disconnects, Fuses, Circuit Breakers, Meters, Controls, Wires); Interior Distribution Equipment (Conductors, Raceways, Conduit; Subpanels, Submeters, Wires); Loads (Lighting, Motors, Equipment, Etc); Back-up Equipment (Generator, Fuel Storage, Transformer, Transfer Switch, Circuit Breakers, Meters, Controls)
6.2.2	Nonstructural	Building Utility Systems (Water)	Pumps; Boilers; Storage Tanks; Piping; Fixtures
6.2.3		Building Utility Systems (Natural Gas)	Service Pipe; Meters; Valves; Pipes
6.2.4	Nonstructural	Building Utility Systems (Steam)	Boilers; Pumps; Pipes; Valves; Steam Traps; Collection Tanks;
6.2.5	Nonstructural	Building Utility Systems (Sanitary Drainage)	Drains; Piping
6.2.6	Nonstructural	Building Utility Systems (Storm Drainage)	Drains; Piping; Cistern; Gutters; Downspouts
6.2.7	Nonstructural	Building Utility Systems (HVAC)	Fuel Tank; Boiler; Pumps; Coils; Fans; Dampers; Ducts; Filters; Chiller; Pipes; Valves; Cooling Tower; Registers; Diffusers; Controls
6.2.8	Nonstructural	Building Utility Systems (Medical Gas)	Tanks; Bottles; Manifold; Pipes; Valves; Pressure Regulator; Outlets; Controls; Monitors; Alarms

Table U.2 continued

6.2.9	Nonstructural	Building Utility Systems (Medical Air)	Medical Air Compressor; Filter; Dryer; Receiver; Pipes; Valves; Outlets; Controls; Monitors
6.2.10	Nonstructural	Building Utility Systems (Central Vacuum)	Receiver; Pumps; Pipes; Valves; Outlets
6.2.11	Nonstructural	Building Utility Systems (Mass Notification)	Central Control Unit; Battery Backup; Strobes; Speakers; Wiring
6.2.12	Nonstructural	Building Utility Systems (Security)	Detectors; Sensors; Alarm Indicators; Controls; Cameras; Monitors
6.2.13	Nonstructural	Building Utility Systems (Communications)	Wires; Coaxial Cable; Servers; Telephones; Televisions; Radios; Computers; FAX Machines; Pagers
6.2.14	Nonstructural	Building Utility Systems (Fire Detection and Alarm)	Detectors; Pull Stations; Control Panels; Firefighter Communications System; Public Emergency Reporting System; Alarm Indicators
6.2.15	Nonstructural	Building Utility Systems (Fire Suppression)	Sprinkler Heads; Piping; Pumps; Storage Tanks
6.2.16	Nonstructural	Building Utility Systems (Elevator, Cable / Electric / Traction)	Hoistway; Pit; Penthouse; Car Stop Buffer; Car; Elevator Doors; Hoistway Doors; Cables; Counterweight; Motor; Rollers; Guide Rails; Motor Drum Brake; Guide Rail Brake
6.2.17	Nonstructural	Building Utility Systems (Elevator, Hydraulic)	Hoistway; Pit; Car; Elevator Doors; Hoistway Doors; Motor; Pump; Control Valve; Oil Reservoir; Oil; Hydraulic Piping; System Controls
6.3	Nonstructural	Building Contents	Computer Equipment; Communications Equipment; Food Service Equipment; Laundry Equipment; Medical Equipment; Pharmaceuticals; Medical Supplies; Medical Gas Cylinders; Library Stacks; Shelving; Cabinets; Furniture; Movable Partitions; Lockers; Vending Machines
7.0	Lifeline		Electrical; Water; Natural Gas; Steam; Sanitary Sewer; Storm Sewer; Communications

Table U.2 continued

7.1	Lifeline	Electrical	Generating Plant; Transformers; Long-Distance, High-Voltage Transmission Lines; Substation Transformers; Local Transmission Lines; Pole Transformers
7.2	Lifeline	Water	Source; Treatment; Storage; Main Distribution Lines; Submain Distribution Lines; Branch Lines; Manholes; Valves
7.3	Lifeline	Natural Gas	Source; Wells; Compressor Stations; Transmission Pipelines; Market Hubs; Storage Facilities; Vehicles
7.4	Lifeline	Steam	Generating Plant; Main Distribution Lines; Manholes; Valves; Customer Service Lines
7.5	Lifeline	Sanitary Sewer	Lateral; Street Main; Branch Trunk Sewer; Trunk Sewer; Interceptor; Manhole; Lift Station; Treatment Plant; Outfall; Discharge
7.6	Lifeline	Storm Sewer	Drop Inlet; Street Storm Water Main; Branch Trunk Storm Sewer; Trunk Storm Sewer; Interceptor; Manhole; Lift Station; Discharge
7.7	Lifeline	Communications	Two-Way Radio System (Radio Terminals/Portable Radios/Mobile Radios/Fixed-Station Radios, Base Station/Repeater, Antenna System, Switching System/Controller, Site Link, Network Management System); Public Switched Telephone Network (Telephone Lines, Fiber Optic Cables, Microwave Transmission Links, Cellular Networks, Communication Satellites, Undersea Telephone Cables, Switching Centers); Cellular Network (Portable Transceivers/Mobile Phones/Pagers, Base Stations, Transmitting Towers, Telephone Exchanges/Switches)

Table U.2 continued

7.8	Lifeline	Solid Waste Collection	General Waste; Medical Waste; Recycling
8.0	Supply Chain		Raw Materials; Manufacturing; Warehousing; Vehicles;
9.0	Transportation		Roadways; Rail Lines; Bridges; Tunnels; Air Traffic Control; Traffic Signals
10.0	Community Services	Fire Protection; Law Enforcement; Child Care	
10.1	Community Services	Fire Protection	Fire Vehicles; Fire Personnel; Dispatch Capability
10.2	Community Services	Law Enforcement	Law Enforcement Vehicles; Law Enforcement Personnel; Dispatch Capability
10.3	Community Services	Child Care	Child Care Personnel; Child Care Facilities

Table U.3 identifies the dependencies and influences associated with each system. These relationships are also reflected in the influence diagram.

Table U.3: Dependencies and Influences

ID	SYSTEMS	DEPENDENCY	INFLUENCE
1.0	Community	Functional Hospitals	
2.0	Hospital Services; Personnel; Structural Systems; Nonstructural Systems	Lifelines; Supply Chain; Transportation	Community Disaster Response
3.0	Hospital Services	Hospital Staff; Structural Systems; Nonstructural Systems	Functional Hospital
3.1	Hospital Services	Hospital Staff; Structural Systems; Nonstructural Systems	Functional Hospital
3.2	Hospital Services	Hospital Staff; Structural Systems; Nonstructural Systems	Functional Hospital
3.3	Hospital Services	Hospital Staff; Structural Systems; Nonstructural Systems	Functional Hospital
3.3.1	Hospital Services	Building Utility Systems; Building Contents; Supply Chain; Transportation	Hospital Services; Building Utility Systems;

Table U.3 continued

3.3.2	Hospital Services	Medical Logistics (Fuel); Communications; Transportation Lifeline	Hospital Services
3.4	Hospital Services	Hospital Staff; Structural Systems; Nonstructural Systems	Functional Hospital
4.0	Personnel	Transportation	Hospital Services; Nonstructural Systems
5.0	Structural		Hospital Services; Nonstructural Systems
6.0	Nonstructural	Hospital Staff; Structural Systems; Lifelines; Supply Chain; Transportation	Hospital Services
6.1	Nonstructural	Structural Systems; Building Utility Systems	Hospital Services
6.2	Nonstructural	Hospital Staff; Structural Systems; Building Contents (Computer Equipment, Communications Equipment); Medical Logistics; Lifelines; Supply Chain; Transportation	Hospital Services
6.2.1	Nonstructural	Electrical Lifeline; Medical Logistics (Fuel); Hospital Staff (Operations and Maintenance); Structural System	Hospital Services
6.2.2	Nonstructural	Water Lifeline; Electricity; Medical Logistics (Fuel); Hospital Staff (Operations and Maintenance); Structural System	Hospital Services
6.2.3		Hospital Staff (Operations and Maintenance); Natural Gas Lifeline	Hospital Services
6.2.4	Nonstructural	Water Lifeline; Electricity; Medical Logistics (Fuel); Hospital Staff (Operations and Maintenance)	Hospital Services
6.2.5	Nonstructural	Sanitary Sewer Lifeline	Hospital Services
6.2.6	Nonstructural	Storm Sewer Lifeline	Hospital Services
6.2.7	Nonstructural	Electricity; Water; Fuel; Communications; Staff	Hospital Services
6.2.8	Nonstructural	Electricity; Communications; Medical Logistics	Hospital Services
6.2.9	Nonstructural	Electricity; Communications; Medical Logistics	Hospital Services
6.2.10	Nonstructural	Electricity; Communications	Hospital Services
6.2.11	Nonstructural	Electricity; Communications	Hospital Services
6.2.12	Nonstructural	Electricity; Communications	Hospital Services

Table U.3 continued

6.2.13	Nonstructural	Electricity; Communications Lifeline	Hospital Services
6.2.14	Nonstructural	Electricity; Communications; Hospital Staff (Operations and Maintenance); Fire Department	Hospital Services
6.2.15	Nonstructural	Water; Electricity/Fuel/Steam (power for pumps)	Hospital Services
6.2.16	Nonstructural	Electricity; Hospital Staff (Operations and Maintenance)	Hospital Services; Hospital Staff
6.2.17	Nonstructural	Electricity; Hospital Staff (Operations and Maintenance)	Hospital Services; Hospital Staff
6.3	Nonstructural	Building Utility Systems	Hospital Services
7.0	Lifeline		
7.1	Lifeline	Communications Lifeline	Building Utility Systems
7.2	Lifeline	Electrical Lifeline; Communications Lifeline	Building Utility Systems
7.3	Lifeline	Electrical Lifeline; Communications Lifeline; Transportation	Building Utility Systems
7.4	Lifeline	Water Lifeline; Electrical Lifeline; Communications Lifeline	Building Utility Systems
7.5	Lifeline	Electrical Lifeline; Water Lifeline; Communications Lifeline	Building Utility Systems
7.6	Lifeline	Electrical Lifeline	Building Utility Systems
7.7	Lifeline	Electrical Lifeline	Building Utility Systems
7.8	Lifeline	Communications Lifeline; Transportation	Medical Logistics; Hospital Services
8.0	Supply Chain	Lifelines; Transportation	Medical Logistics; Medical Transportation; Building Contents; Building Utility Systems
9.0	Transportation	Lifelines	Medical Logistics; Medical Transportation; Building Contents; Building Utility Systems
10.0	Community Services		
10.1	Community Services	Water Lifeline; Communications Lifeline; Transportation	Hospital Services
10.2	Community Services	Communications Lifeline; Transportation	Hospital Services
10.3	Community Services	Lifelines; Transportation;	Hospital Staff

Table U.4 identifies the goals and characteristics of effectiveness for each of the systems. These help us understand what we expect from the systems and how we might measure their success or failure in achieving those expectations.

Table U.4: Goals and Characteristics of Effectiveness

ID	SYSTEMS	GOALS	CHARACTERISTICS OF EFFECTIVENESS
1.0	Community	Maximize availability of hospitals for community disaster response.	
2.0	Hospital Services; Personnel; Structural Systems; Nonstructural Systems	Maximize availability of hospital delivered healthcare during disruptions.	
3.0	Hospital Services	Maximize availability of hospital services.	
3.1	Hospital Services	Maximize availability of treatment services.	Capacity; Availability; Throughput; Quality
3.2	Hospital Services	Maximize availability of ancillary services.	Capacity; Availability; Throughput; Quality
3.3	Hospital Services	Maximize availability of support services.	Availability; Capacity; Agility (responsiveness)
3.3.1	Hospital Services	Minimize service disruptions. Minimize supply chain disruptions. Maximize alternate sources of service provision. Maximize geographic diversity of sources of service provision.	Flow; Availability; Capacity; Agility (adjusting to supply and demand changes); Sustainability (repeatable and consistent processes)
3.3.2	Hospital Services	Minimize service disruptions. Maximize alternate modes of transportation. Maximize number of available vehicles.	Availability; Capacity; Agility (adjusting to supply and demand changes)
3.4	Hospital Services	Maximize availability of administrative services.	Availability; Capacity; Agility (responsiveness)

Table U.4 continued

4.0	Personnel	Maximize availability of staff. Maximize alternate sources of staffing. Minimize role conflict among staff members. Maximize flexibility in organizational structure (i.e., line of succession, delegation, flexible assignments, etc.). Maximize cross training among staff members. Maximize common core training among staff members.	Availability; Training; Organization; Agility (responsiveness to changes in demand)
5.0	Structural	Minimize damage to structural systems.	Integrity
6.0	Nonstructural	Maximize availability of nonstructural systems.	
6.1	Nonstructural	Minimize damage or loss of architectural elements. Minimize debris.	Access to Spaces; Availability of Spaces
6.2	Nonstructural	Maximize availability of building utility systems.	
6.2.1	Nonstructural	Minimize service disruptions (i.e., blackouts and brownouts). Maximize alternate sources of service provision.	Current; Voltage; Quality (Continuous Current)
6.2.2	Nonstructural	Minimize service disruptions. Maximize alternate sources of service provision.	Flow (volume/time); Pressure; Aesthetic Quality (Odor, Taste, Appearance); Contaminants; Specialized Quality (pH Balance, Ionization)
6.2.3		Minimize service disruptions. Maximize alternate sources of service provision.	Flow; Pressure; Quality (Contaminants)
6.2.4	Nonstructural	Minimize service disruptions. Maximize alternate sources of service provision.	Flow (volume/time); Pressure; Contaminants
6.2.5	Nonstructural	Minimize service disruptions (i.e., capacity, clogs, line breaks, etc.). Maximize alternate sources of service provision.	Flow
6.2.6	Nonstructural	Minimize service disruptions. Maximize alternate sources of service provision.	Flow
6.2.7	Nonstructural	Minimize service disruptions. Maximize alternate sources of service provision.	Flow; Pressure; Temperature; Humidity; Aesthetic Quality (Odor, Appearance); Contaminants

Table U.4 continued

6.2.8	Nonstructural	Minimize service disruptions. Maximize alternate sources of service provision.	Flow; Pressure; Quality (Contaminants)
6.2.9	Nonstructural	Minimize service disruptions. Maximize alternate sources of service provision.	Flow; Pressure; Quality (Contaminants)
6.2.10	Nonstructural	Minimize service disruptions. Maximize alternate sources of service provision.	Flow; Pressure; Quality (Contaminants)
6.2.11	Nonstructural	Minimize service disruptions. Maximize alternate sources of service provision.	Signal; Signal Quality (Clarity; Volume)
6.2.12	Nonstructural	Minimize service disruptions. Maximize alternate sources of service provision.	Signal; Signal Quality (Visual Clarity, Audible Clarity; Volume)
6.2.13	Nonstructural	Minimize service disruptions. Maximize alternate sources of service provision.	Signal; Signal Quality (Clarity; Volume)
6.2.14	Nonstructural	Minimize service disruptions.	Signal; Signal Quality (Visual Clarity, Audible Clarity; Volume)
6.2.15	Nonstructural	Minimize service disruptions.	Flow; Pressure
6.2.16	Nonstructural	Minimize service disruptions.	Responsiveness; Movement; Load Capacity
6.2.17	Nonstructural	Minimize service disruptions.	Responsiveness; Movement; Load Capacity
6.3	Nonstructural	Minimize damage or loss of building contents. Minimize debris.	Access to Equipment and Supplies; Availability of Equipment and Supplies
7.0	Lifeline		
7.1	Lifeline	Minimize service disruptions.	Current; Voltage; Quality (Continuous Current)
7.2	Lifeline	Minimize service disruptions.	Flow (volume/time); Pressure; Aesthetic Quality (Odor, Taste, Appearance); Contaminants
7.3	Lifeline	Minimize service disruptions.	Flow; Pressure; Quality (Contaminants)
7.4	Lifeline	Minimize service disruptions.	Flow (volume/time); Pressure; Contaminants
7.5	Lifeline	Minimize service disruptions.	Flow
7.6	Lifeline	Minimize service disruptions.	Flow
7.7	Lifeline	Minimize service disruptions.	Signal; Signal Quality (Clarity; Volume)
7.8	Lifeline	Minimize service disruptions.	Availability; Capacity

Table U.4 continued

8.0	Supply Chain	Minimize supply chain disruptions. Maximize sources of raw materials. Maximize geographic diversity of manufacturing and warehousing facilities. Maximize the number of vehicles.	Flow; Capacity; Agility (adjusting to supply and demand changes); Sustainability (repeatable and consistent processes)
9.0	Transportation	Minimize transportation disruptions. Maximize alternate routes.	Flow; Availability; Capacity; Connections
10.0	Community Services		
10.1	Community Services	Minimize service disruptions.	Availability; Capacity; Capability; Organization
10.2	Community Services	Minimize service disruptions.	Availability; Capacity; Capability; Organization
10.3	Community Services	Maximize availability of child care services.	Availability; Capacity; Capability; Quality

Appendix V

OPERATIONALIZING THE HAZARD VULNERABILITY MITIGATION FRAMEWORK

The expert panelists suggested that identifying examples for the categories, sub-categories, and characteristics within the Hazard Vulnerability Mitigation Framework was a necessary step in operationalizing the framework. Table V.1 is an attempt to start that effort. The list is not comprehensive.

Table V.1: Examples for Sub-Categories and Characteristics within the Hazard Vulnerability Mitigation Framework

Hazards		
Natural		
Earthquake	Tsunami, tidal wave	Volcano
Mass wasting, landslide, mudslide, subsidence	Flood, external	Severe thunderstorm
Snowfall, blizzard, ice storm, hail	Temperature extremes	Hurricane
Drought	Wildfire	Dam inundation
Epidemic	Insect infestation	Food-borne illness
Windstorm, dust storm, sand storm	Lightning strike	Electromagnetic pulse
Asteroid		
Technological		
Levee failure, dam failure	Sewer failure	Information systems failure
Electrical failure	Steam failure	Fire, internal
Generator failure	Fire alarm failure	Flood, internal
Transportation failure	Communications failure	HAZMAT exposure, internal

Table V.1 continued

Fuel shortage	Medical gas failure	Supply shortage, fuel shortage
Natural gas failure	Medical vacuum failure	Structural damage, structural failure
Water failure	HVAC failure	Radiological exposure, external
Water contamination	Chemical exposure, external	Radiological exposure, internal
Supply chain interruption		
Human-Induced		
Mass casualty incident (trauma)	Hostage situation	Terrorism, radiological
Mass casualty incident (medical/infectious)	Civil disturbance	Terrorism, chemical
Mass casualty incident (HAZMAT exposure)	Labor action, strike	Terrorism, explosive
VIP situation	Forensic admission	Terrorism, biological
Infant abduction	Bomb threat	Warfare, bombardment, blockage, siege
Workplace violence	Cyber attack	
Agents and Characteristics		
Agents		
Water	Wind	Ground shaking
Fire	Loss of ground integrity	Explosive force
Excessive heat or cold	Hazardous material	Difference between supply and demand
Component failure		
Speed of Onset		
Measured in terms of time, disaster events are commonly known as slow onset or rapid onset.		
Scope of Impact		
Measured in terms of geographic area or the range and depth of activities affected, the greater the scope of impact, the more disruptive an event tends to be.		
Duration of Impact		
Measured in terms of time, this is the length of a disruption. It may be measured in hours, days, weeks, months, or years.		

Table V.1 continued

Frequency of Impact		
Measured in terms of time, this is how often a disaster event impacts an area or entity. Frequent disaster events tend to be more salient in our memories while less frequent events may be forgotten. Frequent experiences may also precipitate protective action.		
Length of Warning / Existence of Environmental Cues		
Measured in terms of time, this is the amount of time between knowing about an event and the impact. Environmental cues may provide an indication of an impending disruption. Advances in technology have increased the length of warning available for some disaster events, while others surprise us.		
Exposure		
See the Spaghetti Diagram at http://udspace.udel.edu/handle/19716/12903. This model reflects the systems, components, interactions, and dependencies necessary to maintain a functional hospital.		
Vulnerabilities		
See the Table of Objectives in Appendix U. This table identifies characteristics of effectiveness that represent ways in which systems, components, and relationships between them can be affected by disruptive events.		
Consequences		
Fatality		
Deaths of people		
Injury or Illness		
Injuries to people	People with illnesses	
Mental Distress		
Stress	Depression	Anxiety
Service Loss		
Utility disruption	Supply chain disruption	Transportation disruption
Business disruption (e.g., health care delivery)		
Financial Loss		
Loss of physical money	Loss of physical items with monetary value	Expenditure of money associated with rebuilding or relocating
Property Loss		
Loss of structures	Loss of land parcels	Loss of material goods

Table V.1 continued

Loss of Reputation		
Loss of future customers, loss of future patients	Loss of potential employees	Loss of business opportunities
Cost of Adjustments		
Costs associated with mitigation	Costs associated with preparedness	Changes to insurance costs
Mitigation and Preparedness		
Robustness		
Flood gates, submarine doors	Design against progressive collapse	Blast resistant windows and frames
Comply with applicable building codes and regulations, but also consider whether those minimum requirements are sufficient protection against relevant threats.		
Redundancy		
Emergency generators	Elevated back-up water tanks	Extra medical or general supplies on-hand
Multiple vendors	Extra equipment on-hand	Cross trained staff members
Rapidity		
Personnel recall rosters	Organizational flexibility to create response teams	
Resourcefulness		
Emergency operations center to coordinate disaster response	Organizational flexibility to mass personnel and other resources against a disruptive event	
Adaptability		
Apply lessons from past exercises and disaster events to mitigation and preparedness activities.		
Avoidance		
Do not put critical systems or functions in the basement of a facility subject to flooding or storm surge.		