THREE CONTEXTS OF PLANNING AND DECISION ANALYSIS FOR DISASTER MITIGATION IN HOSPITALS: TAIWAN, VANCOUVER, and LOS ANGELES

by

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Abstract

This thesis investigates the impact of power and water outages caused by both electrical grid failure and natural disasters on the operational capacity of hospitals in three case studies: 1999 Chi-Chi Taiwan Earthquake, Vancouver, and Los Angeles.

Using a case study methodology and review of the literature, the study attempts to characterize the types of impacts that are likely to result from power and water outages and how the concurrent impacts of disaster may exacerbate the impacts.

Beyond characterizing impacts, the study also investigates the role different regulatory environments play in decision-making. Decision analysis tools are used to illustrate the inter-connected nature of decision-making in disaster mitigation and to identify opportunities to improve outcomes and increase disaster resilience in hospitals.

Decision-making outcomes about disaster mitigation are a combination of compliance with legislative standards and financial resources allocated to risk mitigation measures. Dissonance between desired outcomes and actual outcomes frequently arises because of lack of information about the impacts of power outages, budgetary decision-making, and lack of coordination in strategic planning and day-to-day operational choices.

The results of the study indicate that while hospitals have made significant strides in disaster preparedness they remain extremely vulnerable to the impacts of power and water outages. Moreover, hospitals lack systemic, detailed information on the probability of a total failure occurring and have in general failed to plan in detail for a scenario where emergency power systems fail.

To improve resiliency at hospitals and reduce vulnerability to power and water outages several steps are necessary. First, regulatory and accreditation bodies ought to develop a database to monitor and track the frequencies of outages, the performance of back-up measures, and the outcomes on patient care. Data for metrics such as duration of the outages, patient deaths, patient discharges, cancelled surgeries, financial impacts exist today, but are not reported systematically. Second, reducing hospital vulnerability to power and water outages ought to be a community priority for disaster mitigation planning and provide funding necessary for mitigating the impacts of power and water outages.

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Glossary of Abbreviations

AHA	American Hospital Association
CEPR	Centre for Emergency Preparedness Response
CGMH-L	Chang Gung Memorial Hospital Linkou
CHA	Canadian Hospital Association
CHA	Canadian Health Act
CHW	Catholic Healthcare West
CSA	Canadian Standards Association
EERI	Earthquake Engineering Research Institute
ED	Emergency Department
EM-DAT	Emergency Disasters Data Base
EMS	Emergency Medical Services
EOC	Emergency Operations Centre
EPSS	Emergency Power Supply System
DART	Disaster Assistance Relief Team (DART)
FDD	Facilities Development Divisions (within OSHPD)
FEMA	Federal Emergency Management Agency
GDP	Gross Domestic Product
JCAHO	Joint Commission on Accreditation of Healthcare Organizations
ICU	Intensive Care Unit
MCEER	Multidisciplinary Center for Earthquake Engineering Research
MMI	Modified Mercalli Intensity Scale
MPE	Maximum Probable Earthquake
NBBC	National Building Code of Canada
NHMC	Northridge Hospital
NFPA	National Fire Protection Association
OR	Operating Room
OSHPD	Office for Statewide Health Planning and Development
PBX	Private Branch Exchange (phone equipment)
PCH	Puli Christian Hospital
PEP	Provincial Emergency Program (British Columbia)
SAIDI	System Average Interruption Duration
SB-1953	Senate Bill 1953
SPH	Saint Paul's Hospital, Vancouver
UPS	Uninterrupted Power Supply

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Chapter One: Introduction and Problem Statement

1.1 Introduction

Disaster preparedness is an issue that has rapidly worked its way up the urban agenda in recent years. Traditionally, disaster preparedness has been the domain of the military and civil defense organizations but the growing complexity of urban regions and magnitude of risk has broadened the focus of disaster planning from merely preparedness to a more holistic, mitigation-focused discipline. Moreover, recent years have witnessed a series of well-publicized events that have taxed the ability of existing response measures and reinvigorated the search for more proactive mitigation programs aimed at preparing for disasters in order to reduce their impacts, rather than simply increasing response capability to deal with an emergency ex-post.

Broadly, this new approach can be understood in terms of sustainable hazard mitigation. The goal of sustainable hazard mitigation is to foresee, manage, and mitigate losses from future natural disasters so that these hazards will not jeopardize the long-term well-being of human settlements. Sustainability is an elusive concept which aims to reconcile the needs of the present while preserving the ability of future generations to secure their needs.[1] Defining a desirable quality of life in the face of natural hazards forces communities and decision-makers to make difficult decisions, to trade-off present benefits in favour of uncertain future benefits. Sustainable hazard mitigation hinges upon the ability to understand, articulate and achieve an appropriate balance between benefits and risk in the present day with future benefits and risks. Social tolerance of risk varies over time, across society, and especially with the nature of the risk itself. The dynamic nature of risk and risk tolerance requires stakeholders to pursue the "systematic evaluation of alternative courses of action, so that the approach chosen to reduce vulnerability is an optimal solution

[1] Burby, Raymond J. "Natural Hazards and Land Use: An Introduction" in *Cooperating with Nature: Confronting Natural Hazards with Land Use Planning for Sustainable Communities* 1998 Washington, D.C.: Joseph Henry Press, p. 1

given a community's present circumstances, future prospects, and the goals and aspirations of residents."[2] Consequently, this approach to disaster preparedness explicitly links development patterns, social choices, and decision-making in order to address increasing losses from natural disasters. In other words, this approach seeks to link "wise management of natural resources with local economic and social resiliency, viewing hazard mitigation as an integral part of a much larger context.[3]

Writing in 1975, White and Haas declared that natural hazards are "extreme, low probability meteorological or geological phenomena that have the potential to cause disasters when they strike human collectives."[4] Natural hazards include extreme weather (typhoons, floods, ice storms), seismic events, (earthquakes, volcanoes, tsunamis) and epidemics to list only a few. Labeling these events as 'natural hazards' is somewhat misleading as many of these 'hazards' also create positive environmental benefits to natural systems. For instance, hurricanes, an essential component of regenerating and flushing the marine ecosystems in the Florida Everglades, are a prominent example of the potential benefits of events termed 'natural hazards.'[5] Other events such as forest fires are often referred to as natural disasters even though they are a necessary component of many forest ecosystems.[6]

A second problematic aspect of this term is that these events are only hazardous when they occur in areas of human settlement or activity. Prior to the advent of global seismic monitoring networks, most of the earth's two million earthquakes went unnoticed by humans and posed no threat. Seismic risk has not increased because of significant changes in the geology of the Earth. Rather, seismic vulnerability has increased because of human decisions such as poorly constructed buildings and higher density communities on seismically

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[2] Burby, Raymond J 1998 p. 2
[3] Mileti, Dennis 1999 *Disaster by Design* Washington, D.C.: Joseph Henry Press p. 2
[4] Mileti, Dennis 1999 p.22
[5] La Corte, Rachel "Francis stirred up Florida's Environment" AP Press, September 7, 2004 [Accessed September 8, 2004] Available online at: http://www.msnbc.msn.com/id/5930983/
[6] Parks Canada "Time for Nature" 2004 [Accessed July 14, 2004] Available online at: http://www.pc.gc.ca/canada/nature/archives/2003/dec/index_E.asp

active areas of the earth's crust.[7] Disaster management efforts that emerge from this perspective have pursued the unrealistic goal of controlling and shaping natural processes to suit human settlements such as the failed Project STORMFURY efforts of the late 1960s.[8]

Natural disasters occur at the nexus of complex anthropogenic systems and equally complex natural systems; thus according to Dennis Mileti and others, "disasters are the result of the collective policies and decisions made by society in planning land use and design and construction of buildings and infrastructure."[9] To date, the dominant approach to the threat of natural hazards has been to issue warnings before a disaster occurs, technological hazard reduction measures, and emergency relief after a disaster strikes.[10] While each of these efforts is essential to any hazard mitigation plan, they have often resulted in unanticipated outcomes that are increasing vulnerability, rather than reducing it. Consider hurricane warning. Increasingly reliable hurricane warnings have increased vulnerability by offering a false sense of security, and by extension, increasing development pressure on prime waterfront properties. Coastal development in areas vulnerable to this hazard have proliferated, increasing the human and financial vulnerability to these storms.

Structural efforts to reduce vulnerability have also been only partly successful; work by Sheaffer et al in 1976 found that two thirds of US flood losses resulted from flood events that exceeded the design limitations of structural flood control measures.[11] Moreover, climate change researchers point out that as the global climate changes, many parts of the world are likely to suffer more extreme weather than in the past, increasing the likelihood that flood events

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[7] Committee on the Science of Earthquakes Living on an Active Earth National Academy of Sciences Washington, D.C. 2003 p. 11

[8] Willoughby, H.E., J.A. Clos, and M.G. Shoreibah (1982): "Concentric eye walls, secondary wind maxima, and the evolution of the hurricane vortex" in *Journal of Atmospheric Science* 39, pp.395-411

[9] Petak, William J. "EERI 2003 Distinguished Lecture: Earthquake Mitigation Implementation: A Sociotechnical System Approach" 2003, www.nd.edu/~eeriund/Speakers/Petak%20abstract.pdf

[10] Burby, Raymond J. Cooperating with Nature: Confronting Natural Hazards with Land-Use Planning for Sustainable Communities Joseph Henry Press 1998 p. 4

[11] Sheaffer, John R. et al *Flood Hazard Mitigation Through Safe Land Use Practices.* 1976 Chicago: Keifer and Associates

will exceed the design parameters of structural mitigation measures. Not only have these measures only provided partial protection, but they have also exacted a significant environmental cost. Thousands of rivers and coastal areas have been channelized or hardened in an effort to reduce flooding, a great expense to the natural environment of those ecosystems. As noted by Raymond Burby, the shift to more sustainable approaches to hazard mitigation began in 1950, when an American government commission argued that flood losses could be reduced by "keeping people out of the flood's way" rather than "trying to keep the flood out of people's way."[12] The challenge of hazard mitigation is to extend this line of reasoning to include all natural hazards, and re-conceptualize long-held views of disasters as "Acts of God" to an "emphasis on the human ecological interactions that can generate disaster."[13]

1.2 The Extent and Impact of Disasters

Changing patterns of human settlement are increasing vulnerability to disaster. Globalization, industrial restructuring, and emerging communications technologies have spurred rapid urbanization in massive urban conglomerations best described by Scott as "city regions" expanding into their urban peripheries.[14] The combination of increasing population density and physical urban expansion into more vulnerable areas has placed increasing numbers of people at risk to wind damage, storm surges, floods, landslides, and seismic danger. The consequences of these trends are emerging in the disaster data reported by EM-DAT. Figure One demonstrates how the number of people affected by disasters has risen sharply since the 1960s, roughly as increased urbanization took hold in all corners of the globe. This data clearly supports Mileti's contention that efforts

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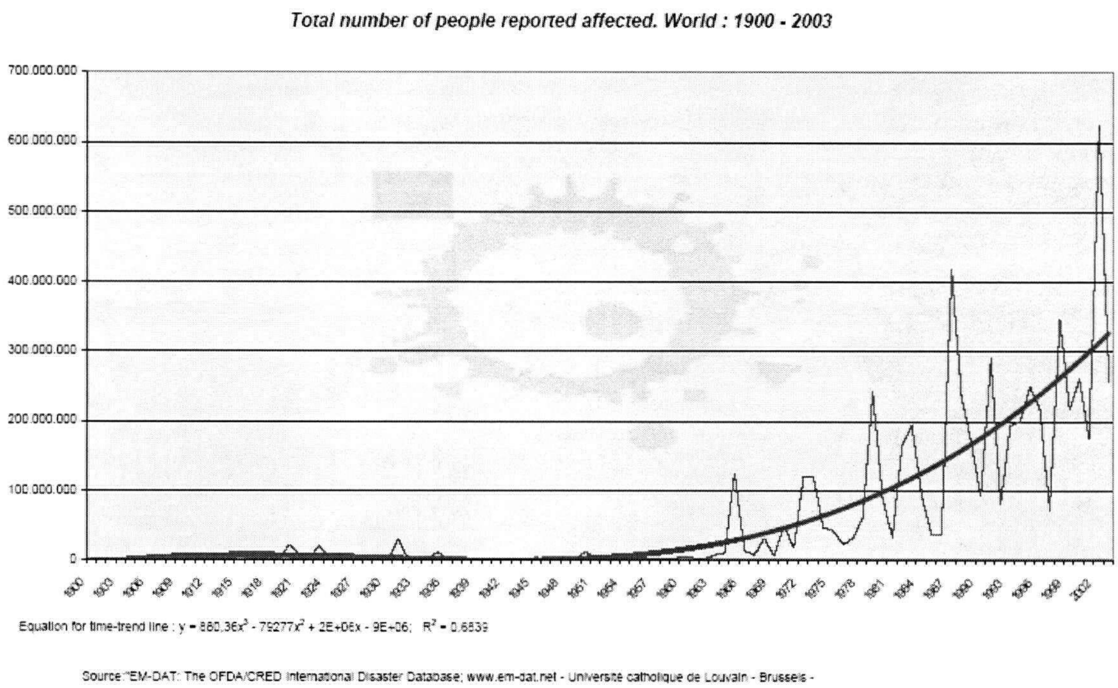
[12] Burby, Raymond, 1998 p. 9

[13] Mitchell, James K. "What's in a name?" Issues of Terminology and Language in Hazards Research" in *Environmental Hazards* 2 (2001) 87-88 p. 87

[14] Scott, Allen J., John Agnew, Edward W. Soja and Michael Storper. 2002. "Global City_Regions." In *Global City_Regions* by A.J. Scott, Ed. Oxford, UK: Oxford University Press.

to reduce risk through technical mitigation efforts have failed to reduce society's vulnerability to natural hazards because changing social patterns have more than offset any gains made through purely technical mitigation efforts.

<u>Figure One: Total Number of People Affected by Disasters (World) 1900-2003</u>



Source: http://www.em-dat.net/documents/Trends/totaffalldis.pdf

The growth in the number of people affected by natural disasters is indicative of the population growth in vulnerable regions. Already, over three quarters of the world's population living in more developed regions lived in urban settlements, often in areas vulnerable to natural hazards.[15] In the United States, 75 million people and 50 percent of that nation's building stock ($8.6 trillion) are located in areas prone to damaging earthquakes; FEMA estimates annualized losses to be more than $5.6 billion per year (2003 dollars), with a potential loss in

[15] UN Habitat, http://www.unhabitat.org/habrdd/statannexes.htm

excess of $100 billion from a single significant earthquake.[16] These figures do not consider other areas of the US vulnerable to different types of disasters such as wind storms, flooding and winter storms.

A disaster resilience framework shifts the emphasis of disaster mitigation from risk analysis to vulnerability analysis. Risk is simply the possibility of an unwanted event occurring, yet in itself risk is not necessarily an indication of danger. To better illustrate the distinction between risk and vulnerability consider the hospital context. Hospitals are dependent on a continuous supply of electrical energy to fulfill their operational mission. As hospitals do not control most of the circumstances that affect the reliability of electrical power, there is little that they can do to alter the risk of power failure. However, they can substantially reduce their vulnerability to power outages by investing in reliable electric power and water back-up systems. Thus, reducing vulnerability means taking action to reduce the likely impacts of risk, a cornerstone of long-term, sustainable disaster mitigation. Investments in technology and effective planning and staff training are the keys to reducing vulnerability by emphasizing "... organizational and human factors problems associated with the implementation of mitigation technology."[17] Put simply, for most vulnerabilities hospitals face, there are solutions for mitigating much of this risk; what is lacking is a holistic understanding of the vulnerability and the motivation to address this and move toward disaster resilient hospitals.

In spite of the growing awareness of the threat from natural disasters, ongoing public apathy limits the scope of preparation and risk mitigation. While there is some anecdotal evidence of a shift in public attitudes toward disaster preparedness after the 2004 Tsunami and 2005 Hurricanes Katrina and Rita, it is too early to dismiss well-documented and long-standing public apathy to the threat of natural disasters. Erik Auf der Heide's work Disaster Response: Principles of Preparation and Coordination provides useful insight into understanding the causes behind this apparent lack of concern. Surprisingly, Auf

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[16] Committee on Seismology and Geodynamics, National Research Council, "Improved Seismic Monitoring – Improved Decision-Making: Assessing the Value of Reduced Uncertainty" 2005 p. 1
[17] Petak, William J. 2003

der Heide's research indicates that a simple lack of awareness of the risks from natural hazards is the primary reason for a lack of action. Frequently, this lack of awareness is reinforced by political actors, such as the infamous presidential statement that "no one thought the levees would fail" in New Orleans, despite years of research indicating just that.[18] Of greater concern though, Drabek's 1986 research of the 1971 San Fernando earthquake found that less than half the population living in the affected area made preparations for future earthquakes.[19] Auf der Heide points out that public perception of risk and actual risk show no correlation, and that risk is consistently downplayed.[20] Related to unrealistic risk perceptions are psycho-social responses to the threat of natural disasters such as fatalism and denial. For many, natural disasters are conceived as "Acts of God" or acts of nature to which human society cannot respond nor prepare for. In large part, the ongoing expansion of development in highly vulnerable areas of the world reflects the strength of these attitudes toward disaster.

Yet, the lack of effective disaster preparation is not simply due to human psychological responses to low-probability, high-impact events. A good deal of the responsibility for the current lack of disaster preparation lies on the shoulders of disaster researchers themselves. Writing in 1989, Auf der Heide points out that the difficulties of articulating the benefits of disaster preparation make it vulnerable to budget cuts during times of fiscal restraint.[21] The most obvious example of this ongoing trend were the cuts to the US Army Engineering Corps' budget to maintain the levees protecting New Orleans just two months prior to Hurricane Katrina.[22] While the budget cuts are unlikely to have substantially

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[18] Froomkin,Dan "A Dearth of Answers" in *Washington Post* Thursday, September 1, 2005 Available online at: http://www.washingtonpost.com/wp-dyn/content/blog/2005/09/01/BL2005090100915.html

[19] Drabek, T. E. Human system responses to disaster: an inventory of sociological findings, New York, 1986, Springer-Verlag p. 24

[20] Auf der Heide, Erik "Disaster Response: Principles of Preparation and Coordination" 1989, http://orgmail2.coe-dmha.org/dr/Static.htm Chapter Two

[21] Auf der Heide, 1989, Chapter Two

[22] Donze, Frank "City Council to Empower Katrina Committee" in *Times-Pacayune* Friday, September 30, 2005 Available online at: http://www.nola.com/newslogs/tporleans/index.ssf?/mtlogs/nola_tporleans/archives/2005_09.html

contributed to the disaster, they do illustrate how short-term cost-savings can outweigh the long-term savings mitigation can produce.

In order to continue to advance disaster mitigation, it is essential to link it to other urban research and social values (i.e. economics, environmental sustainability), and to better characterize how disasters impact society. Current disaster research methodology struggles to report the true impact of disasters on society, in part because data is often incomplete, but also due to the contrary impact of some measurement metrics used to measure the well-being of society. For example, Gross Domestic Product or Gross Regional Product, widely watched measures of economic performance frequently increases immediately after a disaster as aid monies poor into the stricken region and residents and businesses invest in replacing goods lost in the disaster. Clearly, GDP does not accurately report the losses experienced during the disaster.

Other attempts to measure impacts of disaster are more promising, but still inadequate. Indicators that focus on lost income and business impacts capture some aspects of the devastation wrought by natural disasters. However, it is arguable that this fails to capture the full-extent of social impacts because the most adversely affected businesses may have closed and therefore not counted in these studies. Moreover, methodological problems pose serious challenges for researchers using this data, as it is extremely difficult to accurately disentangle the impacts of a disaster on the local economy from other economic and social changes.

One way to begin to better illustrate the consequences of disasters and the need for improved disaster mitigation is to reduce the scope of inquiry to focus on a specific element of the impacts of disasters on communities. A great deal of the literature about disasters can be divided into two categories. The first focuses on the general aspects and nature of natural disasters, mitigation and recovery. The second generally investigates the impacts of a specific disaster upon a specific community. The limitations on the former include the scope of their endeavour and the necessary lack of specifics from which planners and others can implement the approaches put forward in these works. For the latter, the difficulty is that the impact of a significant disaster are complex, occurring across a wide spatial and temporal frame, in addition to a myriad of differential impacts on communities and businesses within the region impacted b the disaster.

The goal of this thesis is to understand the impacts of disasters, specifically those causing power and water outages in hospitals, in order to better understand the decision environment faced by disaster planners in a specific social context as opposed to a specific disaster context. This thesis addresses vulnerabilities faced by hospitals in terms of infrastructure dependence by focusing on how emergency planners perceive the threat, the actions taken to mitigate it, and how decision-analysis may be applicable to further mitigation of this vulnerability.

1.3 The Role and Vulnerability of Hospitals in Disasters

While disasters are a problem globally, responding to the immediate needs of post-disaster victims remains an intensely local concern. In the critical 72 hours after a major disaster, local officials and emergency care providers are tasked with the critical responsibility of rescuing and treating the bulk of critical victims. The operational status and capacity of hospitals to respond to this type of emergency is a crucial factor in the community's vulnerability to disasters. Consequently, mitigating threats to hospitals such as the loss of critical infrastructure such as water and power supplies is essential.

Hospitals perform a critical function in society, especially in the aftermath of a natural disaster. "The objective of medical preparedness for emergencies is to be able to meet the imbalances that arise between needs and available resources in the event of a major accident or disaster."[23] Moreover, hospitals must be equipped and prepared to perform this role in the critical 72 hours after a disaster when it is quite likely critical infrastructure has failed. Experience in the Great Hanshin earthquake in Kobe, Japan and Hurricane Katrina have

[23] Essinger, Kaj and Bengt Linder "Disaster Medicine in Europe: Organization and Trends " http://www.hope.be/07publi/leaflet/disaster/frame.htm

demonstrated the critical need for local capacity to respond to these challenges, as it typically takes at least twenty-four hours for outside assistance to arrive at the disaster site and assist local authorities. Changes in healthcare have prolonged and improved the lives of millions, thereby increasing its prominence as an essential community service. This increasing dependency mirrors the changes in social expectations that deem any infrastructure failure to be unacceptable, and thus, largely unplanned for in most communities.[24] Hospitals impact communities not only in terms of patients receiving care within the facility, but also through outpatient care of chronic illnesses such as renal care (e.g. kidney dialysis). In a disaster, hospitals would be severely challenged to maintain care for the most seriously ill of their 'normal' patient load in addition to trauma victims of the disaster, all while their capacity could be reduced or crippled because of the loss of lifeline infrastructure such as power and water to the facility. Clearly, as complex human systems in their own right, hospitals provide a context from which one can critically examine Mileti's assertion that "disasters are by design."

In the immediate aftermath of a disaster, hospitals are often the focal points of a community's recovery efforts as a critical part of a community's public safety infrastructure[25] and their performance will contribute significantly to a community's disaster resilience, both in the short term, and over the long-term. Within the emergency services network, hospitals serve as hubs for triaging and treating the wounded, decontamination sites during chemical/biological/radiological events, and as important public communication nodes. Should a major disaster occur in a densely populated urban area, the demand on healthcare facilities could be unprecedented. For example, mortality in the 1994 Northridge earthquake was 3.4 dead per 100 000 people, while in the 1999 Chi-chi quake in Taiwan, mortality reached 116 dead per 100 000. In most emergencies, casualty figures often run at a multiple of ten to the number of

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[24] Tierney, Kathleen Environmental Hazards Washington, D.C. Joseph Henry Press, 2001
[25] Lovern, Ed "How much is enough?" Modern Healthcare, Chicago: Nov. 19, 2001, Vol.31, Issue. 47; p. 4

deaths.[26] Beyond dealing with the immediate influx of wounded and dealing with their own internal emergencies, hospitals must also plan for monitoring and controlling the spread of infectious diseases within their facilities in conditions that make sanitation an extreme challenge. The risk of disasters and other causes for mass casualty emergencies is well-understood within the healthcare community. Yet most planning and preparation is oriented around managing these types of disasters on the premise of fully-operational hospital facilities, a dubious prospect at best.

The ability of hospitals to succeed in this mission will depend on a number of critical factors relating not only to the nature of the emergency and the facility's vulnerability to lifeline infrastructure failures but also to more mundane issues such as existing capacity within the hospital system to absorb the demand surge a major disaster will cause. Already, hospital officials point out that "there is no excess capacity. A moderate-sized event could tip the system over the edge."[27]

Despite its importance, the role of hospitals in an actual disaster may be severely limited if key systems are disabled, or the facility itself is rendered unsafe. In communities all over the world, seismic risk and other threats to lifeline infrastructure have been well documented, and varying progress has been made in ensuring hospital buildings meet basic life-safety standards for local seismic risk conditions. Building codes offer a great deal of seismic risk mitigation, but even here, one must be cognizant of their limitations. For example, decisions about seismic risk are based largely on the concepts maximum magnitude and Maximum Probable Earthquake (MPE).[28] Thus, even with full compliance with building codes, uncertainty exists both in the accuracy of the MPE estimate, and the ability of the structures to perform as designed. In Canada, the most applicable building code for hospitals is NPCC-1995, which

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[26] Seligon, H.A. and K.I. Shoaf. ."Human Impacts of Earthquakes". In W.-F. Chen and C. Scawthorn (eds.), Earthquake Engineering Handbook, CRC Press, Boca Raton, Florida. 2003
[27] Lovern, Ed, Nov. 19, 2001, Vol.31, Issue. 47; p. 4 3 pgs
[28] Earth Consultants International "Technical Background Report to the Safety Element of the General Plan, City of Glendale" 2003 Available online at: http://www.glendaleca.com/government/planning/safety_element/TBR_Cover--Introduction_Table_of_Contents.pdf

includes a 10% probability that an earthquake that exceeds its design guidelines will occur in any fifty-year period.

Hospitals, like all other nodes of modern infrastructure systems, are increasingly reliant on distributed infrastructure networks that are vulnerable to disruption during a natural disaster precisely when the services offered by hospitals are at their greatest demand. In consideration of this, hospitals have invested in back-up systems and technology to help ensure their reliability. Yet a review of the literature demonstrates that in previous disasters and emergencies, back-up infrastructure has failed sometimes to perform as designed, with reason to believe that will occur in future disasters.[29] Only in rare instances are the back-up capabilities equal to those of normal operations. Furthermore, there is substantial uncertainty about the effects of reduced power and water supplies on hospitals under longer-term outages that are possible in a severe disaster scenario. This uncertainly must be considered in making decisions about appropriate back-up capabilities, maintenance standards, and planning to respond to the medical demands that will emerge in the aftermath of a large disaster.

Hospitals provide an important example of how growing complexity can increase vulnerability to lifeline infrastructure interruptions. To paraphrase one hospital emergency planner, a hospital without power and water becomes little more than a dysfunctional hotel, incapable of delivering healthcare and more than likely a disaster site in its own right.[30] For example, by August 29, less than 24-hours after Hurricane Katrina made landfall, New Orlean's main public and private hospitals, Charity Hospital and Tulane University Hospital, were both forced to begin evacuating patients as flood waters threatened Emergency Power Supply System (EPSS).[31] Thus, in the midst of an unprecedented

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[29] Kile, James C., Stephen Skowronski, Mark D. Miller, Stephan G. Reissman,, Victor Balaban, Richard W. Klomp, Dori B. Reissman, Hugh M. Mainzer, Andrew L. Dannenberg "Impact of 2003 Power Outages on Health and Emergency Response" in *Pre-hospital and Disaster Medicine* March-April 2005 http://pdm.medicine.wisc.edu

[30] Arnold Soria, Supervisor, Plant Operations, Providence Holy Cross Medical Center, Interview by Darren Cole, 5 October, 2005

[31] Meserve, Jean, John Zarrella and David Mattingly "Katrina Gone but Impact Continues" August 30, 2005 Available online at: http://www.cnn.com/2005/WEATHER/08/30/katrina.impact/

disaster, Charity Hospital, the region's only Level 1 trauma center for 350 miles was offline, unable to assist stranded residents in need of medical care.[32] While hospitals have made significant investment in limited emergency back-up infrastructure, most hospitals remain unprepared for an emergency, lacking essential components of an emergency plan such as where and how patients will be evacuated, how hospitals will coordinate and communicate with other emergency organizations if normal communications are disrupted and how the hospital will communicate with the community to help manage demand for healthcare post-disaster.[33] Moreover, in seismically vulnerable regions it is particularly important that hospitals plan for prolonged outages, and prolonged periods without external help. If key transportation and communications infrastructure fail, hospitals may need to operate beyond 72-hours on emergency back-up, something that few are prepared to do at this time.

Assessing the impact of lifeline outages on hospital performance during an emergency is crucial for emergency planners and would facilitate better planning in a number of ways. First, knowing what the impacts are likely to be will facilitate planning that will include a more accurate estimate of how hospitals will perform under emergencies. Second, by understanding the impact of power and water outages on hospitals, it may be possible to identify opportunities for mitigating these vulnerabilities and improve emergency performance. Last, by better understanding the impacts of lifeline infrastructure outages on hospital performance it may be possible to fine-tune loss-avoidance regulations and design standards to ensure that safety requirements are adequately—but not excessively—met.[34]

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[32] Schneider, Andy and David Rousseau "Address the Health Care Impact of Hurricane Katrina" (Report #7387) Kaiser Commission on Medicaid and the Uninsured. Available online at: http://www.kff.org/uninsured/upload/7387-2.pdf
[33] Susan Shamban, Manager, Occupational Health & Safety, Northridge Medical Center, Interview by Darren Cole, October 4, 2005
[34] Committee on Seismology and Geodynamics, National Research Council, "Improved Seismic Monitoring – Improved Decision-Making: Assessing the Value of Reduced Uncertainty" 2005 p. 6

1.4 Research Questions

The goal of this thesis is to answer the following questions:

1. How would water and power outages affect hospital service and capacity?
2. How could this impact be mitigated?
3. How could decision analysis tools be applied to help understand mitigation strategies?

Understanding the impact of power and water outages on hospital capacity would enable disaster planners and other decision makers insight into the severity of these events on the capacity of the in-situ healthcare system to respond to the medical needs of the disaster impacted community. In turn, this will influence broader emergency planning issues such as the importance of medical evacuation, the need for mobile hospitals to be established in disaster-affected areas, and further investment in reducing hospital vulnerability to these outages.

Preparing for and responding to power and water outages is an essential condition for, but not primary to, a hospital's primary mission. Decision makers are consequently faced with conflicting objectives where long-term disaster resilience must be traded-off against short term, mission-focused healthcare services. Once the impacts of power and water outages can be more accurately characterized, it is possible to consider potential trade-offs to mitigate the impact of these outages. Question three focuses on how decisions are made, and how decision analysis can be usefully applied to complex decision context of hospital emergency preparedness. By gaining an improved understanding of who makes decisions, how decisions are made and in what context, this thesis will develop a decision-making framework from which a better understanding of the tradeoffs in risk mitigation strategies can emerge.

The aim of the research is to understand the potential impacts and vulnerabilities of hospitals to lifeline infrastructure failure and to understand the decision opportunities for mitigation. To achieve this, three regional case studies located in Taiwan, Vancouver, Canada, and Los Angeles, United States respectively, have been identified to answer the research questions. The Taiwan case study has been selected because of the 1999 Chi-Chi earthquake that caused widespread power and water outages across the island. The Vancouver case study focuses on an older hospital and illustrates the challenges and decisions faced by hospitals in preparing for the uncertain impacts of power and water outages on their facility. Los Angeles offers the opportunity to investigate hospitals that have had both fairly recent experience dealing with power and water outages and stringent regulations regarding emergency preparedness.

It is important to appreciate that while each region is unique and cannot be directly compared, important insights can be gained by synthesizing the different experiences of each region in one analysis. The spirit of this approach can be understood much like Edward O. Wilson's conception of consilience as " . . .the linking of facts and fact based theories . . .to create a common groundwork of explanation . . ." and the challenges of this approach seen as " . . .the prospect of intellectual adventure . . ."[35] The challenge is to combine the diverse experiences and realities of emergency planning in the three locations and to distill their essences to a coherent understanding of vulnerability of hospitals to power and water outages, and the ways in which decision analysis can contribute to reducing this vulnerability.

The thesis will proceed by reviewing the literature to characterize academic understanding of both the disaster resilience framework and decision analysis. Next, a Chapter Three includes a discussion of the method used to develop the data of the thesis. Next, the analysis portion of the thesis will begin with an overview of the impacts of the 1999 Chi-Chi earthquake on hospitals in Taiwan, emphasizing post-disaster impacts and adaptation. In analysis will continue by investigating the status of emergency planning for power and water outages in Vancouver and Los Angeles. The emphasis here will be to look at the

[35] Wilson, Edward O. Consilience Random House, 1998 p. 8 and 9

different regulatory and financial contexts of hospitals and how this affects decision-making and emergency preparedness in hospitals.

Chapter Two: Concepts for Understanding Hospital Disaster Resilience

2.1 Overview

The literatures reviewed for this thesis have been wide-ranging in scope and content. In order to understand the impact of power and water outages several bodies of knowledge have been identified for review. However, the study does not focus on the initiating events of the outages, whether human-induced or natural disaster. Thus, a power or water outage occurrence is the starting point for this investigation in terms of preparing for them, their impacts, and opportunities to mitigate negative outcomes of infrastructure failure, regardless of cause.

Resilience is a key concept of emergency preparedness and has been the subject of extensive academic interest and publications focused on disaster research. This arm of disaster research is best summarized by Dennis Mileti's book Disaster by Design, but has been refined and developed by many other researchers working primarily in the domains of social science. This body of work has informed our understanding of the linkages between disasters, social choices and vulnerability and its counterpart, resilience. This body of literature makes an essential contribution to this thesis by placing hospital vulnerability and resilience within the larger context of sustainable disaster mitigation.

A second important element of the literature review has been to understand the hospital decision-making context by looking at its regulatory environment. The focus here has been to develop an overview understanding of who sets standards and regulations for hospital emergency preparedness, the role of oversight bodies such as the Canadian Hospital Association (CHA) and the Joint Commission on Accreditation of Healthcare Organizations. (JCAHO)

A third component of the literature has been to look at the literature relating to decision-analysis. Disaster mitigation decisions represent a classic case of decision-making under uncertainty. Over the past fifty-years, an extensive literature has emerged about common errors made in these types of decisions, and tools which can assist decision-makers make choices that are better aligned with the desired outcomes of those decisions.

2.2 Disaster Resilience

The headlines associated with natural disasters are familiar to even the most casual observer of the daily news. The turmoil of major earthquakes, storms and other natural phenomena often find their way into our collective conscience through powerful images of death and destruction in the press. In spite of the magnitude and drama of these events, the long-term consequences of natural hazards often escape the evanescent eye of the media. While in recent years, developed regions of the world have succeeded in reducing fatalities associated with these events, the economic, social, and environmental impacts have increased to a point where they impinge upon the well-being of many communities. In the face of mounting losses and growing public risk, new concepts of understanding disaster have emerged, most promising of which is known as the "disaster resilience framework."

Vulnerability to hazards is also increasing as forces of globalization, unsustainable land use patterns and urban development have combined to create situations where losses from disaster are increasing at exorbitant rates. Consider that during the 1990s, global economic losses from natural disasters were three times the losses incurred only one decade before, and more than fifteen times the losses incurred during the 1950s.[36] The rising costs of disasters in both human and economic terms demands approaches that can lower long-term, uncertain future costs through better decisions and investments today.

The multiplicity of valid definitions of disaster reminds practitioners of the need for an interdisciplinary focus on implementing disaster mitigation strategies. Dennis Mileti offers the most succinct summary of this approach in six points:

[36] UN Habitat http://www.unhabitat.org/habrdd/statannexes.htm

- Adopt a Global Systems Perspective
- Accept responsibility for hazards and disasters
- Anticipate ambiguity and change
- Reject short-term thinking
- Account for social forces
- Embrace sustainable development principles

Source: Mileti, 1999 p. 12-13

Realizing these objectives will require emergency planning to re-visit many of its fundamental assumptions about disasters and disaster management. Consider the first point, adopting a global systems perspective. How does this apply to the emergency planner at the hospital level? First, it can be as simple as recognizing and acting on the lessons of facilities in other jurisdictions. There is a surprising complacency within many quarters of North American emergency planning that ignores the lessons of similar facilities facing similar challenges in other parts of the world. Another aspect of global systems perspective is for emergency planners in hospitals to be aware of changing demographic trends, infrastructure vulnerabilities and increasing social dependence on healthcare in making decisions about how long their facility must be able to operate when lifeline infrastructure fails.

Accepting responsibility for hazards and disasters affects emergency planning at the hospital level in several important ways. First, site selection is a critical element of a hospital's plan. Frequently, hospitals are located on sites that are inappropriate for such a facility, such as a floodplain or in proximity to known seismic faults. It should not surprise anyone when these facilities fail to perform during an emergency. Second, even modern hospitals often make inappropriate decisions such as locating essential emergency generators in the basements of hospitals built on low-lying land in flood-prone areas. Identifying and accepting responsibility for disasters will enable hospitals to avoid many of the problems they currently face, thereby reducing costs and saving lives in the process.

Anticipating ambiguity and change is an essential, but most difficult task in disaster mitigation. It simply refers to the clichéd question of "How safe is safe enough?" There is no clear answer to this, but it means making decisions with reasonable safety margins. It also means going forward with important decisions when all the facts are not in. All decision-makers prefer more information to less. However, in emergency planning, it is near impossible to identify and prepare for every scenario a facility might face. It also means making decisions that preclude as few as possible future options that may become desirable in the future. Dynamic plans that provide guidance to long-term goals while accommodating the constraints of the organization are essential.

As Mileti's fourth point stresses, the constraints of an organization can lead to a fundamental mistake of short-term planning. For example, from a short-term point of view, it may well seem wise to repair an aging generator rather than investing in new technology. However, with a longer-term view, a new generator may become financially more attractive while offering the significant benefit of more reliable operation during power outages. After all, if a generator fails during a power outage, hospitals face serious financial losses.[37]

Accounting for social forces means that hospital decision-makers understand the expectations of their communities. The consequences of emergency power failure at a large hospital during a disaster could be catastrophic. For politicians and other public decision-makers the results of this may be seen at the ballot box; for hospital administrators and healthcare organizations, the repercussions of this may well be felt through litigation. It also means to work with the community so that a shared understanding of the vulnerability is achieved, reasonable expectations for hospital performance in an emergency are created and channels of communication are opened to develop broader preparedness for dealing with medical emergencies in the wake of disaster.

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[37] Dave Cowan, Facilities Engineer, North York General Hospital, Interview by Darren Cole, 23, March 2005

Embracing sustainable development principles refers to developing holistic solutions that reduce vulnerability to disasters and that can be sustained over the long-term. According to Public Safety and Emergency Preparedness Canada, disaster mitigation is defined as "sustained actions to reduce or eliminate the long-term impacts and risks associated with natural and human-induced disasters."[38] In order to implement sustainable actions to reduce risk, it is important to harmonize short-term constraints and priorities with long-term strategic goals, which is not often easy. Dissonance in decision-making frequently arises not from the callous disregard of information, but in how decision-makers filter and process that information. Clearly, sustainable disaster mitigation strategies must take into account the psychological aspects of our collective understanding of risk.[39]

While planning for hazards has already reduced the annual fatalities associated with natural hazards, the focus should be on devising better methods of limiting the long-term social and economic impacts of disasters on communities. The economic figures described at the beginning of this paper represent a story of lost opportunities. With more effective disaster mitigation strategies, communities can reduce the financial impacts of disasters, improve their natural environments, and better invest in their sustainable futures.

Another concern for sustainable disaster mitigation is that as urban areas grow they will accelerate the degradation of their natural environments. This has had a two-fold impact on natural hazards: 1) Increasing variability in climate. 2) Reducing the natural capacity of the local environment to absorb the impacts of extreme events. Thus, the goal for sustainable hazard mitigation is a moving target; in fact, it is possible that even slow progress toward this goal will still result in ever-rising vulnerability to natural disasters.[40]

Finally, in many hazard-prone regions, private risk-sharing facilities such as insurance are prohibitively expensive. Immediately following a major natural

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[38] Public Safety and Emergency Preparedness Canada http://www.ocipep.gc.ca/ndms/index_e.asp
[39] Smith, 1996. p. 67
[40] National Science Committee, "Living on an Active Earth: Perspectives of Earthquake Science" The National Academies Press, 2003.

disaster, the government and politicians face enormous pressure to compensate victims, regardless if those victims took steps to reduce their vulnerability to known hazards or not. Thus, government is often the de facto insurer of last resort after a damaging event and therefore holds a significant interest in ensuring that effective hazard mitigation does in fact occur.[41] Recovery policies play an essential role in reducing disaster losses in that disaster relief often provides the funding to replicate the original conditions that led to the disaster. Careful recovery planning must occur prior to a disaster happening to ensure in the haste to meet the immediate needs of the community, the long-term needs of that community are met as well. The need for pre-planning post-disaster recovery efforts ought to include major healthcare facilities given their crucial role in community safety.

Limiting economic costs and insuring an equal distribution of the burden of recovery across a community is also the duty of government. Urban planners are uniquely positioned at the crossroads of community participation, government process and expert technical advice. In hazard mitigation, urban planners can serve by coordinating the efforts of disparate members of the community in a people-, not expert-, driven policy. Mileti identifies local sustainability as the central plank of a reformed disaster mitigation regime. Pursuant to this, three of Mileti's six recommendations call for local participation and consensus-drive policies. (Foster local resiliency and responsibility, Recognize that vibrant local economies are essential, Adopt local consensus building)[42] This is essential to overcome what the Committee on the Science of Earthquakes has referred to as the "implementation gap."[43] Mitigation measures must enjoy widespread buy-in within the affected community.

Disaster mitigation, as conceived through the modernist planning agenda of decades past, has succeeded in reducing some risks, or at least postponing them, through the ingenuity of humankind. Yet modern cities are quickly

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[41] Stehr, S.D. "In Harm's Way: Disasters, Public Policy, and the Urban Landscape" in *Urban Affairs Review*, November 1999, vol. 35, no. 2, pp. 301-303(3) SAGE Publications p. 302
[42] Mileti, 1999 p. 6
[43] National Science Committee, "Living on an Active Earth: Perspectives of Earthquake Science" The National Academies Press, 2003. p. 163

reaching the point, if not having already surpassed it, where their reliance on technology and complex infrastructure is now increasing the vulnerability of urban areas to massive disruptions caused by natural hazards. The magnitude of today's urbanization and its reliance on complex infrastructure raises disturbing questions. In his book, The Ingenuity Gap, Thomas Homer-Dixon questions society's ability to resolve our complex problems through reliance on technological and social innovation. He argues that technological solutions for existing problems create new, unforeseen problems while simultaneously increasing the complexity of systems.[44]

In the field of disaster mitigation, we have already witnessed many examples wherein reliance on technology has made the impact of disasters worse, not better. Quoting Smith, ". . . the more a society becomes dependent on advanced technology, the greater the potential for disaster if the technology fails."[45] During the 1998 Ice Storms in Eastern Canada, more than twenty-five people died, mainly due to hypothermia. Dangerous conditions which led to these deaths were created when over one million consumers lost electrical power, some for up to three weeks as a direct consequence of the storm.[46] It is fortunate that in this example communities were not solely dependent on electrical power for home heating. If natural gas infrastructure had experienced a simultaneous failure, the casualties and hardship to people would likely have been much greater. This event and the more recent electrical failures that affected the US east coast and eastern Canada demonstrate that disasters, natural and otherwise, can cripple essential infrastructure over large areas for extended periods of time. Responding to these challenges requires broader action such as diversifying power generation technology and other actions that go well beyond the scope of the present inquiry. However, in the case of hospital emergency preparedness, it is essential to understand and prepare for the

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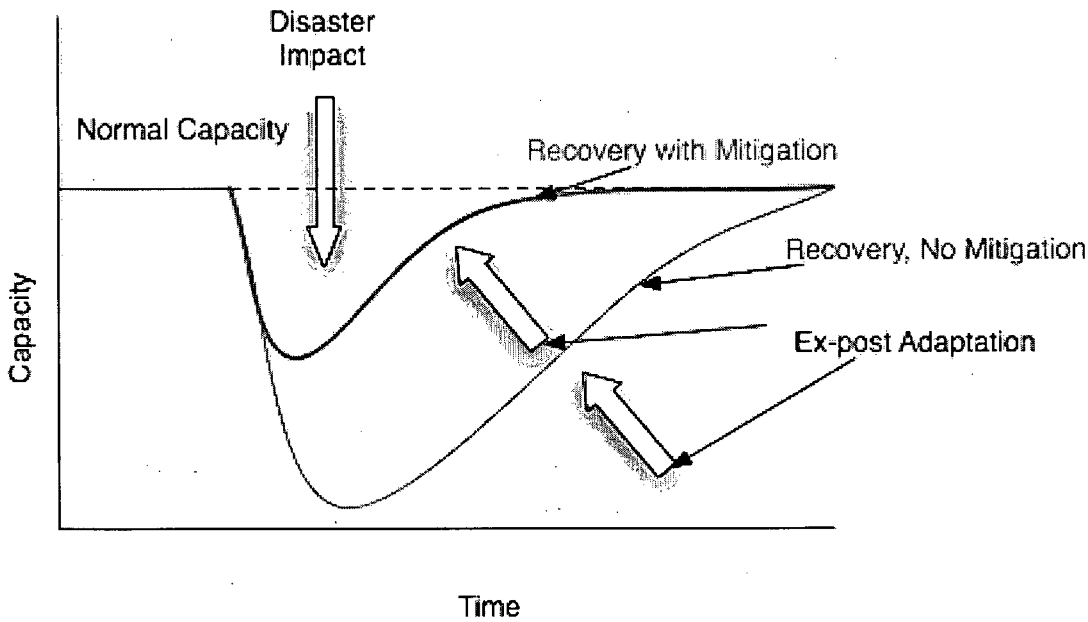
[44] Homer-Dixon, Thomas The Ingenuity Gap: Can We Solve the Problems of our Future? Vintage Canada, Toronto. 2001
[45] Smith, Keith 1996 p. 45
[46] Environment Canada, 2002 "The Worst Ice Storm in Canadian history?" [July 4, 2004] http://www.msc-smc.ec.gc.ca/media/icestorm98/icestorm98_the_worst_e.cfm

impacts of these types of emergencies, as we know they are likely to repeat in the future.

Sustainable disaster mitigation also calls for planning for reconstruction and redevelopment that is necessary after a disaster *before* a disaster occurs. Only in so doing can communities hope to rebuild in ways that will minimize future risks, achieve important social and economic goals, and ensure that development that occurs conforms to the community's disaster mitigation goals. All too often, in the wake of a disaster, the urge to 'return to normal' takes on an irresistible political expediency and many opportunities to reduce future losses from disasters are lost. For example, only five days after the Chi-Chi earthquake, President Lee declared an "Emergency Decree" removing public reconstruction work from the ambit of national urban planning regulations.[47] Planning for fundamental community changes after a disaster ought to include healthcare facilities; for example, fundamental issues such as concentration of healthcare services in a few, well-prepared institutions versus distributing healthcare facilities throughout a community, gaining resilience through geographical dispersal. These are difficult questions that must be considered as part of a community's disaster preparation planning policy. Planning for disasters increases the ability of a community or organization to adapt more quickly, thus increasing their resilience. Resilience enables communities and organizations to both reduce the impacts of disaster and effect recovery more quickly as illustrated in Figure Two.

[47] Chang, Lung-Sheng "The Role of Government and Civilian Assistance in Providing Urgently Needed Social Services and Redevelopment Work in Emergency Situations: The Case of the Recent Earthquake in Taiwan" Council for Economic Planning and Development, Executive Yuan, R.O.C. p. 267 Available online at: http://www.asria.org/farchive1/1104481960/1105353309/Taiwan_921_earthquake.pdf

Figure Two: Resiliency Curve



Adapted from Professor Stephanie Chang

Figure Two graphically illustrates the benefits of effective mitigation in both reducing the intensity of the disaster as measured in terms of lost hospital capacity and in the time to recover to the capacity level that existed pre-disaster. The element of time is particularly important from a community recovery point of view (functional healthcare infrastructure is an essential community service) and from a financial point of view, as diminished capacity greatly reduces hospital income.

Sustainable disaster mitigation requires planning before the disaster, yet, before a disaster, the situation is much like a "wicked problem" in that, in the words of Thomas Birkland, proactive disaster mitigation policies are very much "policies without publics" which results in misguided disaster policies that are based almost entirely on the last disaster.[48] Evidence for the continuance of this trend can be easily found in the massive outpouring of public concern, donations,

[48] Birkland, Thomas A. After Disaster: Agenda Setting, Public Policy and Focusing Events Georgetown University Press, Washington, D.C. 1997 p.49, 51

and media coverage of the 2004 Southeast Asian Tsunami that less than a year into reconstruction efforts has been largely dropped from the international agenda. Moreover, one of the immediate responses to that disaster was the promise to construct a multi-million dollar tsunami warning system that, while useful, will do little to address the prevailing environmental and social conditions that make large segments of the population of this area vulnerable to future, unexpected disasters.

To escape the current trend of planning for the last disaster it is necessary to approach disaster mitigation through a democratic approach that recognizes the subjective nature of risk and provides the right incentives and regulations to empower local communities to manage the trade-offs between mitigation and risk for their communities and society at large. The rapid accumulation of small changes in social systems, economic systems, and environmental systems has created a world of unparalleled complexity. A world that is "in important respects, essentially different from the one we knew in the past, the signposts we used previously to guide our behaviour will not necessarily be good signposts in the future."[49]

2.3 Hospital Disaster Preparedness and Performance

The level of emergency preparedness varies greatly among the three regions (Taiwan, Vancouver and Los Angeles) studied in this report, as well as among individual hospitals within those regions. While substantial differences exist across regions studied in this thesis, even larger intra-regional differences exist; large facilities have more extensive back-up and emergency preparedness programs in place, while small hospitals and second-tier health facilities exhibit substantial vulnerability and lack of preparedness in all regions. In all regions studied in this thesis, the impetus behind emergency preparedness is found primarily in minimum legal requirements necessary to operate as a hospital, with

[49] Homer-Dixon, Thomas 2001 p. 5

professional responsibility and financial reasons as important secondary factors in emergency preparedness.[50]

In Canada, regulation of minimum standards for emergency preparedness is complex with several overlapping agencies and standards. A key standard for most hospitals remains the Canadian Hospital Accreditation Program. Under this program, hospitals are periodically reviewed with emergency preparedness standards as part of this review. Canada has also been a participant in a number of international efforts to develop standards that apply to hospital emergency preparedness such as ISO 9000 and ISO 14000. More recently, the federal government has urged provincial health officials to adopt the CAN/CSA-Z731 standard defined by the Canadian Standards Association(CSA). This standard was finalized in 2003 and is available for purchase from CSA. The standard aims to promote worker safety, reduce the potential for costly damage, assist staff in initiating corrective action, and reduce recovery time and associated costs.[51]

The success of these regulations has been mixed. During the 2003 Northeast blackout in Canada and the United States, most emergency power supplies responded as designed with little impact on patient care in most cases. Furthermore, much of the literature supports the view that emergency power supply systems (EPSS) perform well in outages of short-duration where no damage was caused to the facility. In fact, one author notes that, in the American context, National Fire Protection Association (NFPA) and JCAHO codes and standards "practically guarantee reliable systems."[52] However, according to the same author, Dan Chisholm, experience during the 2003 Northeast power blackout indicated that 1.5% of EPSS systems failed to operate. Of even greater concern is that based on the author's judgment, this figure represents a 50% increase in the failure rate over 1999 data collected by the same author. Added to that concern is the fact most power was restored quickly

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[50] Petak, William J. and Daniel J. Alesch "Organization Decision-making with Respect to Extreme Events: Healthcare Organizations Respond to California's SB 1953"

[51] Canadian Standards Association, "On High Alert and Prepared for Anything" Available online at: http://www.scc.ca/en/nss/success_stories/storydetails_71.shtml

[52] Chisholm, Dan October 2003, 28-34 p. 30

in most of the affected areas, thus not fully taxing EPSS systems during a prolonged outage that could reasonably be expected under certain conditions.

In power outages that stem from natural disasters such as hurricanes and earthquakes, the performance of EPSS systems has been more problematic. For instance, in the 1999 Chi-chi earthquake, no EPSS functioned in Nantou and Taichung counties, meaning that over 1.2 million people were left without a functional healthcare system during the first 24 hours after the quake.[53] The Northridge earthquake in 1994 also revealed systematic weakness in the operation of EPSS and the Earthquake Engineering Research Institute (EERI) identified research into improving EPSS a "high priority."[54] These concerns, along with the catastrophic impact of Hurricane Katrina on New Orleans' hospital system demonstrate how modern cities, and their hospital systems, exhibit extreme vulnerability to lifeline infrastructure failures, especially if they are prolonged.

In spite of the ongoing evidence of the vulnerability of hospitals to lifeline infrastructure failures, much of hospital emergency planning priorities remain focused on responding to a surge of demand caused by disasters that occur outside the hospital facility. These efforts are an extension of emergency planning within hospitals that emphasizes preparation for disasters outside the hospital, not situations where the hospital itself becomes a disaster area. Undoubtedly, these efforts are essential to a hospital's ability to fulfill its essential mission. However, to many observers, the threat of power and water outages has not been addressed: "Some in healthcare have never faced independency from utilities and don't know how devastating an outage can be." [55]

In Canada, the Canadian Hospital Association has documented this creeping complacency in planning for power outages due to the overconfidence

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[53] Professor George Yao, National Cheng-Kung University, Interview by Darren Cole, 23 May 2005

[54] Earthquake Spectra 17, Supplement A (April 2001) -Chi-Chi, Taiwan, Earthquake of September 21, 1999 [2001-02] Chi-Chi, Taiwan, Earthquake of September 21, 1999, Reconnaissance Report

[55] Chisholm, Dan "Energy Crisis? Summer Blackout Demonstrates the Importance of Generator Maintenance" in *Health Facilities Management* October 2003, 28-34 p. 30

in the reliability of EPSS during emergencies.[56] The American Hospital Association's assessment of future investment in emergency preparedness is bleak, forecasting a $98.4 billion dollar shortfall over the five years beginning 2003.[57] To date, few examples of extended power outages affecting hospitals exist save for emerging data from New Orleans. However, the lack of investment in EPSS in American and Canada suggests that EPSS performance in Taiwan after the Chi-chi earthquake may not be an aberration. While no statistical data is available for Canada, interviews with experts in Vancouver indicate the lack of investment in Emergency Planning here is at least as severe as that in America.[58]

Hospitals need not only be prepared to function adequately under EPSS operations, but must also prepare for an influx of patients, even if the source of the outage is a simple outage, not compounded by a natural disaster. For example, one study found that 22% of admitted ED patients in a New York hospital's Emergency Department during the 2003 blackout were electricity dependent chronic homecare patients. The authors concluded that this source of demand has not been adequately considered in most hospital's EPSS planning.[59] In the days after the 2003, some hospitals expressed frustration and anger over the lack of progress in mitigating the risk of electrical outages to hospitals. Jamaica Hospital in Queens lost half of its EPSS due to failure of one of its generators, but still took patients evacuated from facilities with even greater problems. David Rosen of Jamaica Hospital declared "Everybody is blowing generators. I'm shocked at what I'm seeing. And I'm troubled. For all the yelling and screaming that everybody did after 9/11, there is nothing forthcoming to help us shore up this infrastructure.[60] Exploring the reasons for this complacency and

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[56] Hanna, James Disaster Planning for Health Care Facilities The Canadian Hospital Association, Third Edition, 1995 p. 237
[57] Chisholm, Dan 2003 p. 30
[58] Jay Lewis, Terra Firm Inc. Interview by Darren Cole 9 May 2005
[59] Greenwald, Peter W., Anne F. Rutherford, Robert A. Green, MD and James Giglio, MD "Emergency Department Visits for Home Medical Device Failure during the 2003 North America Blackout" in *Academic Emergency Medicine* Volume 11, Number 7 p.786-789
[60] Levy, Clifford, Kate Zernike "The Blackout: Hospitals: Lessons Learned on 9/11 Help Hospitals Respond" in the New York Times, August 16, 2003 (Archived) Available online at: http://select.nytimes.com/gst/abstract.html?res=F60D15FD3E540C758DDDA10894DB404482

potential methods of addressing them will be an important part of the analysis section.

2.4 Documented Impacts of Power Outages: 2003 Northeast Blackout

Despite the effort and investment in back-up power and water supplies, power and water outages continue to effect hospital performance. Even minor outages can have major adverse impacts on patient care due to the sensitivity of major hospital systems such as major instruments and surgical equipment, data centre records, and climate-control apparatus essential to the operation of hospital blood banks.[61]

Obviously, proper maintenance and testing is an essential component of ensuring back-up equipment functions correctly during and emergency. The importance of an effective maintenance policy is demonstrated by the fact that according to hospital engineers, 60-70% of hospital power outages are due to maintenance-related failures.[62] Table One lists EPSS failures and related problems reported by hospitals to the American Hospital Association.

Table One: Summary of Events during the Northeast Blackout[63 64]

Facility	Event	Consequence
Toledo Hospital	No EPSS for centrifuge equipment	Reduced diagnostic lab capacity
Coney Island Hospital	EPSS Failure	Temporary Shut-down
Lockport Hospital	Loss of water	30-minutes on emergency patient diversion until water supply restored

[61] Emerson Power Network "St. Joseph's Hospital Case Study" Emerson Power, http://www.gotoemerson.com/brands/net_power/cs0.html
[62] Emerson Power Network, http://www.gotoemerson.com/brands/net_power/cs0_html
[63] Hounsell, Dan "Fallout" in *Maintenance Solutions* October 2003, Trade Press Publishing http://www.facilitiesnet.com/ms/article.asp?id=1947
[64] Chisholm, Dan 2003 p. 28

Park Ridge Hospital, Rochester	Generator overheated and failed.	Without power for one hour
State of New Jersey, 24 Hospitals on EPSS	No malfunctions reported.	Elective Surgery Cancelled
St. Mary's Hospital, Connecticut[65]	X-Ray machine caught fire after power failed.	Incoming ED patients diverted to alternate facility.
Detroit Medical Center Hospitals[66]	EPSS functioned, but concerns of reliability.	Cancelled Surgeries. Patients ventilated manually.
Downstate Hospital Brooklyn[67]	EPSS failed on several floors.	6 patients evacuated to nearby hospital

It is tempting for some to view the 2003 outage as an indication that all is well with hospital emergency preparedness for power outages. However, researchers have identified several themes that emerged from the outage that warn of ongoing vulnerabilities. For several hospitals just-in-time inventory methods brought them to the verge of a serious shortage of essential supplies.[68] Beyond specific incidents, systematic and potentially cascading failures began to manifest during the outage whose impacts would have amplified substantially under a prolonged outage. For example*:

- Power outages negatively impacted the infrastructure, communications and emergency response
- Communications were limited

[65] American Hospital Association, "Hospitals Appear to be Coping with Power Outage" August 15, 2003 Available online at: http://www.hospitalconnect.com/ahanews/jsp/display.jsp?dcrpath=AHA/NewsStory_Article/data/ann_030815_Outage&domain=AHANEWS
[66] American Hospital Association, 2003.
[67] Warner, Margaret "Power Outage" August 14, 2003 Available online at: http://www.pbs.org/newshour/bb/fedagencies/july-dec03/blackouts_08-14.html
[68] Kile, Skowronski, Miller, et al "Impact of 2003 Power Outages on Public Health and Emergency Response" in *Prehospital and Disaster Medicine* March-April 2005 Available online at: http://pdm.medicine.wisc.edu

- Minimal morbidity due to outages, but hospitals reported the situation might have worsened if the outages had lasted longer
- Hospitals reported lack of preparations and resources for coping with public anxiety
- Additional training in power outage emergencies would have improved responder efforts
- Activation of coordinated control contributed positively to responder efforts

*Adapted from Kile, Skowronski, Miller et al, 2005 p. 95

Selected Examples of Power and Water Outages at Major Hospitals

The Northeast Blackout demonstrates both the risk of widespread power failure and the vulnerability of hospitals to these outages. However, due to the relatively short-duration of the outage, it is difficult to fully understand the potential impacts of power outages on hospitals, especially if these outages are accompanied by a natural disaster. While Hurricane Katrina has painfully demonstrated the potential impacts of cyclonic storms on vulnerable urban areas, it is essential to remember that even lower magnitude events can have catastrophic impacts on healthcare facilities.

In 2001, Tropical Storm Alison dumped over ninety-four centimeters of rain on Houston, Texas over a five-day period, in the process causing the most costly natural disaster in Houston's history.[69] The Hermann Memorial Hospital lay directly in the path of the torrential rains and flooding that resulted from the deluge.

Flooding at the Hermann Memorial Hospital, one of only two level one trauma centres in Houston, caused a complete power outage as water destroyed the facilities back-up generators located in the basement. Level one trauma centers are "institutions statewide that have focused themselves to offer the

[69] National Weather Services Forecast Office "Tropical Storm Allison Floods June 5-9 2001" National Weather Service http://www.srh.noaa.gov/hgx/projects/allison01.htm

highest level of trauma services to Texans critically injured on the highway, at work, at home, or in the community. . ."[70] Figure Three documents the extent of the damage caused by the flooding of the facility. This forced the evacuation of all five-hundred and forty patients from the hospital which involved the assistance of over three hundred volunteers to move patients through darkened stairwells with the aid of only flashlights.[71] Not only was the hospital's emergency back-up equipment located in the basement and vulnerable to the flooding, but also a great deal of the hospital's lab equipment, diagnostic imaging and cardiac equipment was located on the main floor and destroyed during the flooding. This prolonged the facility's recovery and certainly impacted patient care in the Houston area during this time.

The emergency evacuation and closure of the Hermann Memorial Hospital demonstrates how even modern facilities are vulnerable to natural hazards. It demonstrates the critical importance of site selection and a thorough hazards assessment prior to the construction of hospitals. However, even when new facilities are planned and constructed, multiple factors must be considered, meaning it is not always possible nor even desirable to locate facilities on the least risk site. Thus, mitigating these vulnerabilities requires careful consideration and planning of non-structural elements of the facility. For example, had critical EPSS equipment not been located in areas vulnerable to flood waters, the facility would likely have retained emergency power. This would have at minimum facilitated the evacuation by powering emergency lighting and elevators. In addition, by reducing vulnerability to crucial medical equipment that was destroyed by the flooding, the facility might have been able to avoid complete evacuation and continue to offer emergency care to the community. Last, and certainly not least, the investment in planning and risk mitigation would have provided significant cost-savings to the hospital by reducing damage to the

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[70] Amir Dan Rubin, Guy L. Clifton: Survey Reveals Need To Strengthen Financial Viability Of State Trauma System: Texas Trauma System Viability. *The Internet Journal of Healthcare Administration.* 2002. Volume 1 Number 2.

[71] Lezon, Dale "Power Failure forces hospitals to scramble" The Houston Chronicle, June 11, 2001 http://www.chron.com/cs/CDA/ssistory.mpl/front/93724

facility and associated loss of revenue that continued long after the flood waters receded.

Figure Three: Damage at Hermann Memorial Hospital

Source: http://www.bmscat.com/images/img_5853798_HoustonHerman%20Hosp.jpg

The evacuation of the Hermann Memorial Hospital also caused serious impacts at facilities that received the evacuated patients. The Ben Taub General Hospital received most of Hermann Memorial's critical care patients who were transferred by LifeFlight helicopters and ambulance. Ben Taub's infrastructure had not failed, but the hospital was facing staffing issues due to the inability of many of its employees to get to the facility. The influx of patients from Hermann Memorial exacerbated this situation and required nurses at Ben Taub to take on additional patients, and nurses who were already at the facility to remain there and work with limited rest.[72] Another impact of the sudden influx of critical care patients was that staff encountered problems with insufficient equipment such as monitors and IV pumps. The hospital also had difficulty dispensing medications because of the inability of pharmacy staff to get to work."[73] The magnitude of this problem was worsened by the fact that the pharmacy at Hermann Memorial

[72] Williams, Scott "Houston Staff Slosh, dive into evac mode" NurseWeek, http://www.nurseweek.com/news/features/01-06/flood.html
[73] Williams, Scott NurseWeek, http://www.nurseweek.com/news/features/01-06/flood.html

Hospital had been disabled by the power outage, and thus patients were arriving without their required medication.

Houston's experience under Tropical Storm Allison also illustrates the regional impacts of natural disasters and how critical infrastructure failures ripple through the regional healthcare system. A common aspect of most hospital emergency plans is to establish mutual aid agreements with neighbouring facilities, a system that works effectively in small-scale incidents. However, during Tropical Storm Allison, several hospitals declared internal disasters at about the same time. For example, The Methodist Hospital had lost its own pharmacy capacity, food preparation areas, and medical imaging facilities during the disaster and was therefore unable to offer assistance in terms of supplies and capacity to the Ben Taub Hospital as it laboured under the strain of the emergency. Moreover, using LifeFlight helicopters and ambulances to transfer patients from one hospital to another is likely to have seriously impaired emergency rescue services in Houston precisely as the storm was having its greatest impact on the Houston region.

2.5 Regulatory Framework of Emergency Preparedness in Hospitals

In Canada, the legal framework of hospital regulation is a complex tapestry of federal and provincial powers. Under the Constitution Act of 1867 section 92 (5) provinces are given the clear authority for the "establishment, maintenance and management of hospitals."[74] However, due to the federal government's ability to raise tax monies and fund healthcare in Canada, the federal government's Canada Health Act (CHA) has a great deal of influence in how hospitals in Canada operate. The CHA sets out to establish "criteria and conditions related to insured health services and extended health care services that the provinces and territories must fulfill to receive the full federal cash

[74] Department of Justice Canada "Constitution Acts: 1867 to 1982" 2004 http://laws/justice.gc.ca/en/const/c1867_e_html#distribution

contribution under the Canada Health Transfer."[75] The CHA sets out five broad requirements and two conditions that impose minimum standards of health care on the provincial health care systems, define insured services and compensation, and make user charges illegal. Beyond the minimum medical services defined by the CHA, provinces may offer optional services such as pharmacare and ambulance services should they choose to do so. Legally, provincial health care systems are free to ignore the provisions of the CHA, but doing so will prevent them from receiving essential and significant federal funding for the provincial health care system. Given the substantial role of the federal government in healthcare, it stands to reason it also plays a role in decisions relating to hospital emergency preparedness.

The CHA also provides Health Canada's mandate in dealing with emergency preparedness. Health Canada's role in a natural disaster is to "protect the health of Canadians."[76] Many of its direct emergency preparedness responsibilities include stockpiling emergency drugs, coordinating with international health bodies in managing infectious disease, and providing laboratory assistance to provincial health care bodies. In natural disasters, Health Canada's role is to coordinate actions through the Centre for Emergency Preparedness Response (CEPR). This body is designed to serve as a single coordinating point for managing public health emergencies in Canada and establishes federal contingency standards for the delivery of healthcare in crisis situations. It also provides advice to local authorities, and is involved with frontline health workers in identifying what tools are required to respond to an emergency and when an event may require access to the emergency medical supplies it manages.[77]

Universal healthcare implemented by the provincial governments but sponsored substantially by an activist federal health policy presents a unique set of challenges for decision-makers at the hospital level. In order to ensure access

[75] Health Canada, "Canada Health Act Overview" 2005, http://www.hc-sc.gc.ca/medicare/chaover.htm
[76] Health Canada, "Emergency Preparedness" http://www.hc-sc.gc.ca/english/epr
[77] Health Canada, "Emergency Preparedness: Centre for Emergency Preparedness and Response" http://www.hc-sc.gc.ca/english/epr/centre.html

to funding from provincial and federal coffers, hospital administrators must comply with a broad set of responsibilities. Moreover, hospitals are not free to establish fee structures, which potentially place hospitals in a position of growing costs in the face of stagnant or even declining revenues. This constraint was common in all case study regions, even with Los Angeles' private healthcare system wherein health insurance providers are active in determining compensation rates for medical services. After years of cuts to healthcare funding in Canada, only recently have federal and provincial governments begun to increase funding. The result of this has been an increasing strain on the financial underpinnings of healthcare that directly impacts disaster mitigation in several ways. First, hospitals and other healthcare facilities are now operating at or above capacity on a daily basis. There is not a great deal of slack within the system to absorb a sudden influx of patients after a major disaster. Second, the funding constraints have limited the ability of hospitals to pursue strategic mitigation plans as long-range needs have had to been shelved in order to meet immediate exigencies.

Consequently, the decision environment around mitigating the impacts of power and water outages must take into account the financial constraints facing the sector. Funding for emergency planning priorities must compete with other hospital programs for these scare resources.

The United States

Hospital accreditation in the United States is the primary responsibility of the Joint Commission on Accreditation of Healthcare Organizations, (JCAHO) a not-for-profit organization that accredits over 96% of available hospital beds in the United Sates. The JCAHO has been extremely active since 1999 in raising awareness of the need for hospital emergency preparedness, strengthening accreditation standards, and researching innovative ways of achieving these goals. The other important regulatory authority for California hospitals is the Office of Statewide Health Planning and Development (OSHPD). This state government agency is charged with ensuring that California hospitals meet the legislated safety standards defined by Senate Bill 1953 passed in 1994.[78]

Under state legislation, OSHPD is responsible for overseeing facility construction for general acute care hospitals, multi-story skilled nursing homes, and intermediate care facilities in California. OSHPD has a staff of over 200 engineers, architects and construction experts in a group known as the Facilities Development Division (FDD) who review, inspect, and monitor hospital construction in the state of California. The FDD is involved in creating the standards, providing in-depth technical assistance and inspection. The FDD is also involved in post-earthquake damage assessment that determines the safety of continued occupation of the hospital and has the authority to close unsafe facilities. The FDD is not only a technical body; it is advised by the Hospital Building Safety Board that is a citizen advisory board comprised of industry experts in health facility design.

Citizen advisory bodies are part of the JCAHO's general emphasis of the way forward for emergency preparedness in hospitals. The joint commission has noted that hospital emergency preparedness to date has not made sufficient connections with broader efforts aimed at community preparedness. The JCAHO's "Standing Together: An Emergency Planning Guide for America's Communities" emphasizes the need for hospital emergency planners to "remove readiness barriers by providing all communities with strategies, processes, and tools for coordinated emergency management planning."[79] Specifically, it urges planners to define the problem as follows:

1. Define the Community
2. Identify and Establish the Emergency Management Preparedness and Response Team
3. Determine the Risks and Hazards the Community Faces

[78] Office for Statewide Health Planning and Development "Retrofit Program – SB1953" http://www.oshpd.ca.gov/FDD/SB1953/index.htm
[79] Joint Commission on Accreditation of Healthcare Organizations, "Standing Together: An Emergency Planning Guide for America's Communities" JCAHO, 2005 Available online at: http://www.jcaho.org/news+room/press+kits/ems/essesntial_comp_plan_process.htm

4. Set Goals for Preparedness and Response Planning
5. Determine Current Capacities and Capabilities
6. Develop the Integrated Plan
7. Ensure Thorough Communication Planning
8. Ensure Thorough Mental Health Planning
9. Ensure Thorough Planning Related to Vulnerable Populations
10. Identify, Cultivate, and Sustain Funding Sources
11. Train, Exercise, and Drill Collaboratively
12. Critique and Improve the Integrated Community Plan
13. Sustain Collaboration, Communication, and Coordination[80]

JCAHO's "Standing Together" represents a new focus for emergency planning in hospitals. It offers a framework that hospital planners and administrators can adopt to define their priorities and better understand the difficult choices they face. However, there is no legislative requirement that accredited facilities follow the guidelines, and many hospitals lack the funds, expertise or both to implement this planning tool.

2.6 Water and Power Infrastructure Overview

Water and power infrastructures are complex systems with a number of characteristics that make them vulnerable to natural disasters. For instance, in a seismic disaster, many scenarios are possible that would lead to a disruption in potable water supply. One of the most likely scenarios is that while the majority of the water system is intact, it is not operable because of its dependency on electrical power for treatment and pumping. Other scenarios may include failure at critical points in the infrastructure such as a major pumping station, or even worse, the failure of a dam that contains a region's water source. While these, and other failure scenarios lie outside the scope of hospital disaster preparation, it is worth considering for a moment the likely failure scenarios and their

[80] JCAHO, 2005

implications for hospitals. Simply stated, hospital emergency planners must recognize that ". . . electrical transmission and distribution systems cannot be considered reliable following significant earthquakes."[81]

In Canada's emergency preparedness framework, water facilities are considered 'critical infrastructure;' risk mitigation efforts are aimed to "assure the continuation of a sufficient supply of water of suitable quality to meet the needs of Canadians in the face of threats from natural hazards, accidents and malicious attack."[82] The impact of a water system failure would be immediate and lead to cascading impacts. For instance, in the aftermath of earthquake, limited water supplies would impede the ability of the fire department to deal with fires which might result in large number of burn victims presenting at a hospital's emergency department. Significant number of burn victims might quickly overwhelm the hospital's ability to cope; this would be even more true if the hospital itself did not have an adequate water supply that would be needed to support the treatment of victims. Another reason for concern would be the impact on public hygiene and the spread of infectious diseases that could be expected in areas without the adequate water supply necessary to support sanitation. The federal government has only limited capacity to augment potable water supply on an emergency basis through the Department of National Defence's Army Brigade combat engineer units which are similar to the Disaster Assistance Relief Team (DART) which produced 150 000 to 200 000 litres of potable water per day during its relief operation in Sri Lanka, 2005.[83]

The 2003 Northeast power blackout provides a vivid example of how widespread power outages are possible, leaving 50 million people without power.[84] Yet for many, it is tempting to write-off this blackout as a rare event,

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[81] Earthquake Engineering Research Institute, "Earthquake Spectra" Supplement C to Volume 11 of *The Professional Journal of the Earthquake Engineering Research Institute* April 1995 p. 280
[82] Halliday, R.A. "Water, Critical Infrastructure Protection and Emergency Management" Public Safety and Emergency Preparedness Canada, 2003 http://www.ocipep.gc.ca/research/resactivities/CI/2002-D016_e.asp
[83] Canadian Forces, "Canadian Forces Disaster Assistance Team" 2005, Available online at: http://www.forces.gc.ca/site/Newsroom/view_news_e.asp?id=301
[84] Rachman, Tom "Power failure strikes nearly all of Italy; Finger-pointing crosses border" Record, North New Jersey, September 29, 2003.

unlikely to happen again. While these types of blackouts are rare, history suggests they are extremely likely to happen again. For example, North America has experienced three prior blackouts: the 1965 Northeast Blackout, and 1977 Northeast Blackout and the 1996 West Coast Blackouts.[85] Moreover, experts remind us that declining investment in infrastructure maintenance has increased vulnerability due widespread power outages due to weaknesses in the transmission network. Moreover, given the structure of the utility industry, many power outages cross national borders, but coordination of emergency plans and communication rarely do. Wider outages may prolong the length of the outage due to complexity of repair, and they will also make hospital evacuation more difficult because more hospitals, across a wider region, may require evacuation. A similar blackout occurred in Italy in September 2003, affecting 58 million people, plunging almost all of Italy into darkness.[86]

Beyond exceptional events such as those discussed above, electrical power outages can occur for a number of different reasons on a more localized scale. For example, Los Angeles has suffered three widespread electrical outages since September 12's outage that knocked out power to over 2 million customers.[87] The cause of outages such as the Northeast Blackout and the outages in Los Angeles are partly attributed to a lack of investment in maintaining the power distribution network. Deregulating power production and increased public resistance to the installation of new transmissions lines means a more vulnerable power network.[88] Even worse, this situation is unlikely to change, in fact, deteriorate over time as 60% of power customers have indicated they would not accept an additional 1% charge on their power bill to bring failure rates from

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http://powermarketers.netcontentinc.net/newsreader.asp?ppa=8knpq%5FZfjqrnpw%5BUok%27%40%3E%20bfeiZ%21

[85] Siemens Power Transmission and Distribution "Analyzing the Northeast Blackout 2003" 2005 http://www.pti-us.com/pti/2003blackout/blackout.cfm#recentevents

[86] Rachman, Tom 2003

[87] Malnic, Eric and Patrick McGreevy "Power Outage: Here We Go Again" in Los Angeles Times, October 12, 2005 Available online at: http://www.latimes.com/news/local/la-me-outage12oct12,1,1195753.story

[88] Environmental Literacy Council "Electric Power Grids and Blackouts" 2005 Available online at: http://www.enviroliteracy.org/article.php/1277.html

100 minutes (current) to 30 minutes.[89] (System Average Interruption Duration Index SAIDI) To put the one hundred minute SAIDI figure in perspective, in Japan the SAIDI is approximately ten minutes per year.[90]

The collapse of the power grid in the 2003 Northeast Blackout demonstrated the highly interdependent, coupled nature of complex infrastructure systems. A failure on a transmission line in Ohio lead to a ripple effect through power systems in the Northeast, which in turn led to the failure of water supply infrastructure in many Northeast cities due to its dependence on electrical power. Water supply was interrupted in Detroit, Toronto, and Cleveland, which was particularly hard hit, leaving 1.5 million people without water.[91] The water failure can in turn be seen to impact EPSS power systems, such as the Park Ridge Hospital in Rochester, New York. In that instance, back-up generators failed due to overheating caused by a lack of water to cool the system. On average, hospitals were without power for an average of 13 hours during the blackout, almost 6 hours less than the average residential outage period. According to a survey of hospital managers, hospitals began to incur significant financial losses after the outage duration exceeded six hours.[92] Clearly, reliance on distributed infrastructure extends the vulnerability of hospital's critical infrastructure well beyond the facility's site.

Hospital infrastructure is also indirectly threatened by cascading infrastructure failures. For instance, many cities issued boil-water advisories due to a loss of pressure in the water system and increased risk of contamination. While residents who use natural gas as a cooking fuel would have little trouble complying with the order, those dependent on electricity could not. In a hospital environment, the impact of a loss of potable water would be more complex. First, while the loss of potable water would have little impact on essential facilities equipment such as chillers, EPSS cooling, and facility sanitation, potable water is

[89] Ariu, Toshio "Impact of North America Blackout" Central Research Institute of Electric Power Industry, 2004. Available online at: http://criepi.denken.or.jp/en/e_publication/pdf/den398.pdf
[90] Ariu, Toshio Ibid.
[91] CBC News, "Blackout by the Numbers" 2003 http://www.cbc.ca/news/background/poweroutage/numbers.html
[92] Ariu, Toshio "Impact of North America Blackout" Central Research Institute of Electric Power Industry, 2004. Available online at: http://criepi.denken.or.jp/en/e_publication/pdf/den398.pdf

essential for safe operation of critical care services such as operating rooms, kidney dialysis, and burn treatment to name only a few. If a source of potable water were not quickly secured, essential services would be forced to close, limiting the capacity of the facility, or closing it altogether. The other essential element of potable water supply is for staff and patient drinking water, and food preparation. A prolonged potable water outage would make safe, efficient operation of hospital facilities nearly impossible thus making the hospital a disaster site in its own right, drawing on rescue resources, rather than augmenting them.

Another impact of a disruption in potable water is the potential for it to be the cause of increased demand for medical services if there is widespread consumption of the water. The Northridge earthquake disrupted treated water to many water systems in the greater Los Angeles area. The California Department of Health Services issued 'boil water' notices and disseminated this information through local TV and print media.[93] While this was effective in Northridge, without educating the community prior to future disasters, the threat of water-borne illnesses transmitted through untreated water remains a significant public health threat. For hospitals, this might mean a 'second wave' of patients three or four days after the onset of the emergency, at time at which personnel, medical supplies, and EPSS may already be stretched beyond their breaking points.

2.7 Decision Analysis

The decision-making environments of disaster mitigation are as diverse as the diverse nature of environmental hazards. Kathleen Tierney, a leading expert in the field of disaster mitigation notes that "Comparatively little is known about how individuals and organizations choose between available hazard-reducing alternatives."[94] Part of this thesis will be to gain insight about how healthcare organizations make decisions about mitigating losses caused by lifeline

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[93] EERI, Spectra, p.169
[94] Tierney, Kathleen Facing the Unexpected: Disaster Preparedness and Response in the United States Joseph Henry Press, Washington, D.C.2001 p. 79

infrastructure failures. A reasonable assumption to make however is that costs aside, less risk is preferable to more risk in the hospital context. Thus, the decision environment can be characterized into following two questions:

"Who should bear the cost of mitigating hazards?"

"How is a balance to be retained between public responsibility (government) and individual freedom(hospital facility, community etc.)?"[95]

Decision-making and the Need for Decision Analysis in Disaster Mitigation Planning

> Although decision makers try to be rational, they are constrained by limited cognitive capabilities and incomplete information, and thus their actions may be less than completely rational in spite of their best intentions and efforts.[96]

After decades of growth in post-modern epistemology, few pundits of decision analysis would argue that rationality is the guiding force behind decision-making. Yet decision-makers in all facets of public and private life are continually called on to make "the right choice" when faced with complex problems. Decisions about risk mitigation can be understood as "wicked problems" in which "each attempt to create a solution changes the understanding of the problem. Wicked problems cannot be solved in a traditional linear fashion, because the problem definition evolves as new possible solutions are considered and/or implemented."[97] Decision analysis, a field of expertise that traces its origins to soundly modernist, empirical studies of statistics and expected utility, has emerged as a structured approach to managing the complexity of decision-making and offers insight into the trade-offs associated with making choices. Its goal is to assist decision-makers to better understand their values, to be creative

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[95] Adapted from Tierney p.80

[96] March, James G. *A Primer on Decision-making: How Decisions Happen* The Free Press, Toronto, 1994.

[97] CogNexus Institute "Wicked Problems" 2005, http://www.cognexus.org/id42.htm

and develop better alternatives, and to holistically make trade-offs to understand the merits and weaknesses of the alternatives before them.

Working on complex problems is a balancing act between analysis and subjective judgment. One can find many examples in the literature of how an individual, guided by instinct, found great success and achievement. Naturally, we celebrate these successes, and are far more likely to recall these positive examples over examples where instinct has led decision-makers to undesirable outcomes. While instincts are innate and inescapable, and essential, it is also crucial that decision makers be aware of the common pitfalls that these heuristics can lead to. For example, studies by Tversky and Kahneman have demonstrated that humans are far more sensitive to losses than they are to gains. Thus, losing $5 on an investment is seen as worse than making a $5 profit instead of a potential $10 gain.[98] Human nature means that most decision makers are more concerned with success or failure than with gradients of success of failure. Thus we frequently choose solutions that merely satisfices as opposed to maximizes benefits. Maximizing behaviour seeks the best alternative, whereas satisficing involves "choosing an alternative that exceeds some criterion or target."[99] These psychological constraints of human decision-making processes can have particularly serious impacts when thinking about strategies for mitigating risk of natural disasters in hospital settings.

For example, it is easy and logical that decision makers anchor the goal of the mitigation efforts to standards established by the accreditation board or other supervisory agent overseeing hospital emergency preparedness. If one accepts the premise that most decision makers follow some version of satisficing behaviour, one can readily see how the search for alternative mitigation strategies is severely limited. Once an alternative is identified that meets the criterion set out by either the decision makers themselves, or an oversight body, the consideration of further alternatives will cease. This means that another alternative, which may exceed the accreditation standards, at lower cost, and

[98] Kahneman, Daniel and Amos Tversky "Prospect Theory: An analysis of decisions under risk" *Econometrica,* 47:313327, 1979
[99] March, James 1994 p. 18

provide better healthcare during normal hospital operations may never be unearthed. James March refers to this as an "elimination by aspects" model of choice and points out that under this mode of decision-making, decision makers do not consider tradeoffs among various alternatives; instead they eliminate alternatives that do not meet a certain threshold of performance. Contrasting this method of decision-making with that needed to solve wicked problems, one can easily identify its shortcomings.

Ralph Keeney's seminal article "Decision Analysis: An Overview" eloquently puts forth the case for the contribution of decision analysis to improved decision-making and policy results. Keeney also describes a dozen characteristics of the typical "decision environment" faced by decision makers which readily lend themselves to the decision environment faced by hospital administrators making choices about risk mitigation such as multiple objectives, long time horizons, risk and uncertainty.

Keeney puts forth decision analysis as an effective way of dealing with this complex decision environment. Keeney argues that decision analysis is "a philosophy, articulated by a set of logical axioms, and a methodology and collection of systematic procedures, based upon these axioms, for responsibly analyzing the complexities inherent in decision problems.[100] The analysis of decisions about emergency preparedness enables the community to participate in the process, help establish priorities, and weigh necessary trade-offs. Another benefit of documenting decisions through decision analysis is that ex-post, decisions are more understandable, and defensible. For example, if a certain mitigation measure was not undertaken, and a disaster occurred that made this vulnerability painfully evident, hospital officials could better understand and document why the mitigation action was not taken, and incorporate organizational learning to avoid similar mistakes in the future.

Decision analysis can lead to useful insights that result in better decisions. It is important to note that it is not an objective, value-free analysis of a problem that results in an uncontestable optimal 'solution.' Rather, as Keeney points out,

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[100] Keeney, Ralph 1982

its role is to "produce insights and promote creativity to help decision makers make better decisions."[101] Through a creative process, objectives can be defined, values made explicit, and alternatives created that seek to satisfy the objectives of the decision.

Clearly, decision analysis does not lay claim to providing a solution to a decision problem, it merely structures what an ideal solution might look like (objectives) and possible ways to achieve it (alternatives). Another cornerstone of decision analysis is the ability of the analysis to characterize the (un)certainty of achieving predicted results. For example, it may be preferable to choose a mitigation alternative that has a higher probability of success but lower overall utility over an alternative that has a lower probability of success but higher utility. Decision analysis characterizes this as 'expected utility' where the probability of a successful outcome and the level of satisfaction derived from that outcome are combined to provide an overall measure. While working through this type of analysis, it is essential for decision-makers to bear in mind that alternatives ought to lead to their predicted consequences and the decision maker's preference for those consequences.[102]

Decision analysis can disaggregate complexity while maintaining a holistic analysis through the linkages between values, objectives and the creation and evaluation of alternatives for each decision. Several theories exist that attempt to explain how decisions are made, such as March and Olsen's Garbage Can Model where four streams of a problem must come together simultaneously for action to be taken. (Problem agreement, solution to the problem, space on the agenda, one or more persistent advocates.)[103] James March, building on his own work, categorized aspects of organizational decision-making as follows:

1. Problems of attention
2. Problems of memory

[101] Keeney, 1982. p. 821
[102] Keeney, 1982 p. 829
[103] March, J. and J. Olsen *Ambiguity and Choice in Organizations* Universitetsforlaget, Bergen, Norway 1976

3. Problems of comprehension
4. Problems of communication[104]

While these problems affect all organizational decision-making, they are particularly pertinent in terms of mitigating the risk from natural hazards in a hospital setting. First, disaster mitigation must compete for funds with other, more visible problems faced by hospital administrators. For example, long waits for surgery or cancer treatment are far more likely to garner the attention of the news media than inadequate power backup would under typical hospital operations. Second, many hospital administrators and emergency planners alike do not have direct experience with a large emergency such as a damaging earthquake in recent years; while hospital administrators and others recognize the risk, it is arguable whether this knowledge is internalized and acted upon in their day-to-day decision environments. Third, it is difficult to imagine and foresee all potential difficulties that may arise as a result of lifeline infrastructure failure. For example, while it may be obvious how a power outage would affect certain hospital equipment, it is more difficult to assess how the power outage might affect the individuals needed to operate that equipment. Even if the radiology department has sufficient power backup, the department may still not function effectively if an insufficient number of radiologists are unable to reach the hospital due to failures in the transportation network caused by the power outage. Last, hospital operations depend on a number of professions, each operating with its own specialized talent, knowledge, competence and language. As James March points out, decision makers need to find ways to cross these barriers to arrive at an effective decision to meet the multiple objectives inherent to the hospital decision environment.[105]

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[104] March, James G. *A Primer on Decision-making: How Decisions Happen* The Free Press, Toronto, 1994.
[105] March, James . 1976

Heuristics and Other Pitfalls

Max Bazerman's compelling summary of the work of 2002 Nobel Prize winner Daniel Kahneman and Amos Tversky's work on prospect theory illustrates how heuristics can lead decision makers astray. According to Bazerman, heuristics are rules of thumb that reduce the cognitive demands of decision-making and provide decision makers with "efficient ways of dealing with complex problems that produce good decisions a significant portion of the time."[106] In emergency planning, common heuristics range from "everything is ok" to "nothing can be done."

Yet in planning for infrequent events such as seismic disasters, reliance on heuristics can unduly influence the ultimate decision, either in terms of ignoring risk, or an unwarranted response to a threat. Kahneman and Tversky's work points out that one of the most important factors in decision-making is the "availability heuristic;" events that are vivid and recent are more easily recalled, and thus direct attention to decisions about those events. Consider the recent Southeast Asian tsunami that according to the EM-DAT database killed 280, 931 people and affected millions.[107] The vivid, cataclysmic images of this event created an outpouring of public and government relief efforts and were a catalyst for the creation or improvement of tsunami warning systems in the Indian and Pacific oceans. On the other hand, despite progress in recent years in gaining global attention, the global HIV/AIDS epidemic claimed 3.1 million lives in 2004, and still struggles to attract adequate funding, research and treatment programs for the millions of victims.[108] While many other factors such as politics, economics and social factors play-out in the differing global responses to these two disasters, the availability heuristic certainly contributes to an understanding of these differences.

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[106] Bazerman, Max Judgment in Managerial Decision-making Fourth Edition, Wiley 1998. p. 11
[107] EM-DAT: The OFDA/CRED International Disaster Database Université Catholique de Louvain - Brussels - Belgium http://www.em-dat.net/figures_2004.htm
[108] UNAIDS "Global Summary of the HIV/AIDS epidemic 2004" http://www.unaids.org/wad2004/EPIupdate2004_html_en/Epi04_02_en.htm#P16_3133

By focusing on what is most easily recalled, decision-makers can make choices that are not consistent with their overall beliefs. For example, it might be possible to argue that in the case of the Southeast Asian Tsunami, vulnerability to future natural disasters would best be reduced by addressing issues of poverty, inequality and access to education and healthcare rather than sophisticated tsunami warning systems.

<u>Organizational Decision-Making and Disasters</u>

If effective decision-making only involved managing the effects of heuristics and other errors of decision-makers it would already be sufficiently complicated. However, one must also understand the organizational environment of decision-makers and how this impacts decisions. One model of decision-making is one that emphasizes the "logic of appropriateness" in making choices.[109] This theory suggests that rules and identities are the primary basis for decision-making. This is not to say that rationality is not pursued in this model, rather it argues that rationality is a derivative, or consequence, of rule following. Thus, the focus on the 'rationality' of a decision maker is misguided because the rationality of this process is defined and constrained by the rationality of the rules that define the process itself. Given the substantial consequences of errors in decision-making in healthcare facilities, risk mitigation policies are legitimately constrained by internal policies, accreditation standards and past practices. Therefore, to better understand how decisions are made, and to address deficiencies in this process, decision analysts may be well advised to concentrate on the "processes by which identities and rules are created, maintained, interpreted, changed and ignored."[110]

Organizational and personal identities are in constant flux with multiple identities operating simultaneously and perhaps even in conflict. Consider the role of a physician whose identity and decision-making reflect her multiple roles

[109] March, James 1994. p. 57
[110] March, James 1994 p. 57

as caregiver on the one hand while being accountable to the financial constraints of the healthcare facility on the other. Organizations faced by these types of inconsistencies across departments and within individuals themselves, attempt to resolve them through formal training and through informal processes such as role models and mentoring. As new staff are brought into an organization, they quickly learn the organization's cues for an 'appropriate' identity for a particular situation. Thus, future decisions are based strongly on existing rules and identities established within the organization, with the acknowledgement that these rules and identities will change and evolve over time as individuals and organizations adapt. This organizational tendency reinforces individual tendencies for satisficing and rule-following, which may form a barrier to adopting sustainable strategies for disaster mitigation if left unchecked.

One of the most obvious ways that rules change is through experiential learning. Organization learning is an essential ingredient in successful decision-making, but also presents several problems in terms of decision-making relating to disaster mitigation. First, in order to learn from experience, experience must be recalled. For hospitals in Vancouver, there are few experiences that have occurred that will prepare hospitals for potential natural disasters in the future.

Second, even if there were appropriate examples, interpreting the meaning of that experience is essential. Consider the Northridge earthquake of 1994, which was the first earthquake to strike directly beneath an urban area in the United States since 1933.[111] Researchers at the Center for Hazards Research at California State University describe how the historical experience of this disaster has been filtered, profoundly altering the conclusions most frequently drawn from this disaster. The authors of this study point out that even the decision to name the earthquake after the wealthy Northridge area, instead of the lower income Reseda area that was in fact closer to the epicenter, demonstrates how experiences are filtered and re-defined to accord with

[111] Southern California Earthquake Data Center, "Northridge Earthquake" http://www.data.scec.org/chrono_index/northreq.html

dominant beliefs.[112] Clearly, "internal conflict and competition provide a basis for persistent differences in the interpretation of events."[113] Therefore, emergency planners and others interested in decision-making about disasters need to work to frame the problem in terms of choice, not inevitability; that is to understand disasters as "the predictable result of interactions among. . . the physical environment....social and demographic characteristics of communities. . .and the constructed environment."[114]

The competition to define and interpret experience can affect disaster mitigation in hospitals in several ways. Natural disasters such as earthquakes operate on temporal scales well outside that of typical human management structures. Thus, it is possible for some hospital stakeholders to argue that current mitigation efforts have been successful, given the lack of experience in Vancouver, and even if one goes beyond our borders to consider the impact of the Northridge quake, it may be possible to argue that impacts on hospitals were, for the most part, handled acceptably by existing preparation standards given that few casualties or deaths attributed to the failure of hospitals to operate in the aftermath of the earthquake. In total, nine hospitals were closed in the immediate aftermath of the quake, meaning that 2 500 hospital beds were lost.[115] However, others could point out this rosy assessment of hospital performance after the Northridge quake is not justified. The passage of Senate Bill 1953 (SB 1953), which is discussed further in Chapter Five, dramatically increased standards and regulations for seismic disaster mitigation in hospitals. It seems clear based on the legislative response to the closure of nine hospitals during the earthquake that decision-makers in California felt the performance of hospitals were inadequate and took action to address this.

112 Rodrigue, Christine et al. "Construction of the "Northridge" Earthquake in Los Angeles' English and Spanish Print Media: Damage, Attention, and Skewed Recovery" 1997 http://www.csulb.edu/~rodrigue/scehc97.html
113 March, James, 1994. p. 89
114 Mileti, 1999 p. 3
115 DIS Incorporated "Northridge Earthquake" http://www.dis-inc.com/northrid.htm

Good Decisions Start with the Right Problem

"Posing the right problem drives everything else."[116]

The unanticipated, and unwanted result of SB 1953 has been the closure of many hospitals in California that has contributed to a drastic reduction in capacity and access to healthcare.[117] Given the financial strains on the Canadian healthcare system, it is clear that an ill-conceived approach to reducing risk in the aim of improving healthcare could result in a situation here that is similar to that in California. By framing the problem as "How can we make hospitals less vulnerable to seismic damage?" decision-makers in California worked on a problem that was defined too narrowly, creating dissonance between the actual outcome (reduced access to healthcare) and the desired outcome. (lower seismic risk to improve quality and safety of healthcare in disasters)

Decision analysis emphasizes the role of values in making decisions. Values are simply what we care about in the decision context. In terms of reducing seismic risk in hospital settings, it is clear that a core value for any stakeholder must be the improvement of healthcare. Thus, reducing seismic vulnerability is simply a means to a broader objective. Understood in this way, decisions about risk mitigation in healthcare ought to be framed along the lines of "How to we improve access to quality healthcare in the aftermath of earthquakes and other emergencies?" Even better, defining the decision problem would benefit from a wide range of stakeholders' whose values lie at the core of the missions of hospitals in our communities.

Fortunately, hospitals have well-established committee and management structures that facilitate broad consultations and cooperative problem solving and decision-making. The challenge for emergency planners in this environment is to

[116] Hammond, John, Ralph Keeney, Howard Raiffa *Smart Choices: A Practical Guide to Making Better Decisions* Broadway Books, New York 1999 p. 15
[117] William J. Petak and Daniel J. Alesch "Organization Decision-making with Respect to Extreme Events: Healthcare Organizations Respond to California's SB 1953"

raise goals for risk management from beyond nominal compliance in the short-term, where nominal is understood as a 'rule-following' decision model where satisficing legal and accreditation standards are the sole measure of success, to a more sustainable, long-term approach to risk mitigation in hospitals. In other words, it is to adopt a "systematic approach to problems (that) focuses on interactions among elements of a system and on the effects of its interactions…it integrates time, feedback, and uncertainty.[118]

Hospitals have long been aware of the need for multi-stakeholder, multi-disciplinary decision-making structures. In general, a typical emergency planning committee might consist of the following members:

Physician Staff	Administration
Nursing	Emergency Department
Security	Communications
Public Relations	Medical Records/Admissions
Engineering	Maintenance
Laboratory	Radiology
Respiratory Therapy	Risk Management

*List adopted from Drake, 1997[119]

Vancouver Coastal Health Authority hospitals operate a similar committee structures with the innovative addition of community members through the Vancouver Community Advisory Committee. This committee, comprised of members of the public, could facilitate broader representation and engagement with the community to make disaster resilient hospitals integral components of disaster resilient communities. This is crucial to ensure successful mitigation plans, because the community may participate in defining acceptable levels of risk and working toward reducing risk in areas where current vulnerability is

[118] Mileti, Dennis 1999 p. 107

[119] Drake, Denny "Disaster Preparedness" in *Risk Management Handbook for Health Care Organizations* Robert Carrol (editor), Second Edition, American Society for Healthcare Risk Management, 1997

deemed excessive. While opening the process to a wider range or participants, and consequently a wider range of values may complicate risk mitigation in hospitals in the short-term, it is an essential component of accurately framing the problem, and thus, the alternatives that are derived from the decision-making process. Moreover, the literature on multi-stakeholder decision-making is promising; the results of multi-stakeholder decision-making formats clearly demonstrate the potential of applying this technique to hospital risk mitigation decision-making. (Keeney, 1992, Gregory and Keeney 1994, McDaniels 1994)

<u>Decision Analysis and Sustainable Disaster Mitigation in Healthcare Facilities</u>

Once the decision has been framed, decision-makers can then begin the process of uncovering potential alternatives, then weighing the trade-offs implicit in each choice, and ultimately making a selection. It is worth discussing a few aspects of this process that warrant special attention. First, in order to make choices, the performance of each alternative must be measured against the objectives of the decision-makers. This will require a set of metrics upon which to base the evaluation. While quantitative metrics are often easiest to use, it is important to emphasize that objectives need not be quantitative. In the hospital setting, developing metrics to measure the performance of each mitigation alternative is an especially difficult task. In fact, the 2003 Canadian Health Accreditation Report, the Canadian Council on Health Services Accreditation roundly criticized hospitals for a paucity of metrics to analyze their emergency preparedness.[120] The good news is that hospital decision-makers are more likely to squarely address this issue in some way before their next accreditation review due in 2006. However, in interviews in each of the case study regions, emergency planners indicated infrastructure interruptions led to substantial financial losses, particularly if operating rooms were offline. While specifics of these financial losses were not released, it is likely they can justify part of the capital outlay required for further mitigation.

[120] Canadian Council on Health Services Accreditation 2004.

Second, given the complexity of disaster mitigation, changing technological and financial contexts, and an evolving public risk perception, it is essential that disaster mitigation decisions be reviewed periodically through an iterative process designed to support organizational learning and development. Accreditation reviews are undoubtedly an incentive for administrators to review past decisions and work to improve on the results, but emergency planners must go further, and there are rich opportunities for doing so. Careful review of past decisions can help ensure that valuable lessons and organizational learning are not lost. Clearly, emergency drills and other exercises can not only hone a facility's emergency planning, but also provide valuable insight into future priorities that decision-makers ought to consider.

A third critical element of disaster preparedness decision-making is the ability to learn from others. Disasters by their nature are low-frequency high-consequence events, and no facility can be sure of its performance until tested.[121] Yet hospitals fulfill similar operational missions around the world. The diversity of healthcare systems and risks faced by hospitals naturally leads decision makers to make different choices about disaster mitigation plans. Hospitals already participate in regional and international societies designed to share knowledge and best practices in all aspects of their operations. By placing greater emphasis on learning about the impacts of disasters in other areas of the world, local disaster planners can expand their repertoire of mitigation strategies tailored to their specific context. All too often, decision-makers fail to draw lessons from the experiences of others based on the all-too-often incorrect belief that "what happened there could not happen here." Evidence of this abounds, for example, the 1995 Kobe earthquake failed to prod officials in Taiwan to develop emergency plans and the failure of hospitals in New Orleans to learn the lessons of 1991's Tropical Storm Alison's affects on Houston.

Last, effective decision analysis techniques can engage multiple stakeholders in the process, lead to innovative solutions, and create ownership of emergency plans which will improve the effectiveness of such plans during an

[121]Susan Shanbam, Interview by Darren Cole 4 October 2005.

emergency. By engaging multiple-stakeholders in the process of structuring the decision, new relationships can be uncovered that are key to successful implementation of a mitigation strategy. For example, supporting hospital staff is an essential component of a hospital's emergency plan. By providing on-site childcare during an emergency, hospital administrators can reduce the burden on healthcare workers during an emergency who are called upon to not only respond to their family's needs, but the community's as well. Issues such as childcare are likely to be ignored if the decision is framed too narrowly, and the process does not include those who will be responsible for implementing the emergency plan. By framing the problem accurately, thinking about the long-term, and taking strategic action to achieve sustainable disaster mitigation, disaster planners can reduce the impacts of disaster.

Decision analysis does not provide a solution to the risk mitigation challenges facing hospitals. It does however provide a holistic framework from which values can be articulated, objectives defined, and performance of alternatives measured. By structuring the trade-offs, decision-makers can make choices that are consistent, and coherent with their own values and knowledge of the problem. The process also offers the opportunity to re-visit decisions based on new knowledge or changing priorities in a process of review and renewal.

Reducing the vulnerability of hospitals during seismic events or other natural disasters is a key component to reducing community vulnerability to these risks. Too often, decisions to reduce vulnerability are made only after a disaster has occurred. Overcoming this requires a shift in our thinking, to understanding, and internalizing the fact that while we cannot know when the next disaster will occur, disasters are in fact predictable in that they are inevitable. Decision analysis can structure the problem of disaster mitigation so that it can be viewed holistically as part of the hospital's broader organizational mission, allowing trade-offs of dissimilar objectives. For example, how much healthcare service are we willing to trade-off now in order to obtain better healthcare service in a future emergency? The challenges of such trade-off are cognitively and morally complex making structured decision-making and effective stakeholder participation essential to disaster mitigation decisions.

Decision analysis has been applied in various settings relating to risk mitigation for hospitals. A prominent example of the techniques of decision analysis applied to this problem can be found in the report "Renewal by Earthquake: Designing 21st Century Hospitals in Response to California's Seismic Safety Legislation" authored by Wanda J. Jones for the California HealthCare Foundation. Jones sets out with by identifying how decision-makers can approach the cost of compliance with seismic safety standards as choices of:

A) Minimum Cost of Bare Compliance

B) Actual Cost of Projects Stimulated by SB 1953

C) Eventual Booked Cost of the Projects

Depending on how one looks at the problem, the 'logical' approach to ensuring compliance will vary greatly. For example, if a decision-maker chooses to look that the problem through the lens of option A, compliance with the legislation may be achieved at minimal cost, but at the expense of foregoing significant benefits that might be achieved by only slightly higher costs. Interestingly, rule-following seismic safety legislation was originally designed with this belief in mind, that decision-makers would simply invest in minimum compliance through strategies such as building retrofit. It was thought this would produce the best outcome of cost effective vulnerability reduction. However, what quickly became obvious to decision-makers was that this narrow definition of the problem was less preferable to a broader definition that indicated reconstruction, not retrofit, may be preferable. In many cases the costs of reconstruction compare favourably to retrofitting; reconstruction adds the benefits of modern facilities designed for not only optimal seismic safety performance, but also for efficient operations of hospital's primary mission goals. However, when the full-costs of reconstruction are considered, the desirability of this option is clouded for two reasons. First, a 'clean sweep' of replacing old buildings requires either relocation or temporary closure of the facility and loss of revenues while the hospital invests substantial new capital in the facility. Relocating hospitals in urban areas is difficult simply from the point of view of the availability of suitable sites, but also from the community's perspective, as indicated by the controversy of relocated St. Paul's hospital in Vancouver to a new site.[122]

Jones points out a number of factors that must be incorporated in decision-making to create a sustainable, disaster resilient hospital. Her conception of a "21st Century Hospital" lays out several assumptions that relate to the decision context of mitigation, and how decision-makers can identify and better incorporate uncertainty into decision-making. Constraints on hospitals in adjusting to and responding to these changes include a scare workforce, scare capital, and pricing constraints.[123]

Jones goes on to argue that several factors in California encourage suboptimal decisions and investigates the long-term effects of today's decisions. This work contributes to creating a model that can be applied in the context of disaster mitigation for hospitals, but it does not itself address the issue specifically. However, it points out that decisions are necessary and inevitably involve complex trade-offs. By making these trade-offs explicit, and including multiple-stakeholders, it may be possible to arrive at a choice that best reflects the trade-offs decision makers are willing to make to obtain a specified level of risk reduction. Ralph Keeney's safe advice on this topic is as follows:

> The only control that we have is our decision-making. Hence, public policy problems must be structured and understood as decisions. We want to identify and select the best course of action, meaning the one that on balance leads to the best consequences.[124]

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[122] Howell, Mike "Finance Minister Denies St. Paul's Move is a Done Deal" in *The Vancouver Courier* April 27, 2005 Available online at: http://www.vancourier.com/issues05/044205/news/044205nn5.html

[123] Jones, 2004 p. 15

[124] Keeney, Ralph "Framing Public Policy Decisions" in *International Journal of Technology Policy and Management"* 2004 Vol. 4, No. 2 p. 95-115

Influence diagrams are one of the tools used by decision analysis to structure decision elements such as decisions and alternatives, uncertain events and outcomes, and consequences, thus producing a graphical representation of decision situations.[125] Thus, influence diagrams assist in decision-making by representing the choices that need to be made, potential consequences (influence) and graphically include random events (uncertainty) that will affect decision outcomes. Influence diagrams are also particularly useful in depicting decisions with multiple objectives such as emergency preparedness in hospitals. Once constructed, influence diagrams can be used in one of two ways. The first is purely descriptive in nature. However, by understanding the decisions that need to be made and the uncertainly involved, decision-makers can improve their ability to understand more about the problem they face, and the impact of alternatives available to them. A second use of influence diagrams is to 'solve' them. To do so, one must rank potential outcomes in order of preference, and then assign probabilities to the outcomes of decisions that might produce the desired result. The difficulty in applying influence in this diagram revolves around the uncertainty of the data assigned to the probabilities, in addition to the accuracy of ranking the alternatives. For example, in a given decision context, one stakeholder may rank "cost effectiveness" as the most important outcome, while another may rank "implementation time" as the most important objective. Thus, to 'solve' influence diagrams requires a large amount of data and expert opinion in addition to a multi-stakeholder process wherein stakeholders establish agreement on the ranking of desired outcomes by which potential the benefit of potential outcomes will be assessed. Given the constraints of a thesis project, no attempt to 'solve' the influence diagrams presented has been attempted.

Beyond the overall sketch of the decision context of hospital emergency preparedness presented through influence diagrams, decision trees have also been used to explore this question in more detail. Decision trees present decisions in a binary context, only 1 of 2 choices can, and must, be made. As a

[125] Clemen, Robert T. and Terence Reilly Making Hard Decisions Second Edition Brooks/Cole 2001 p. 52

result, the outcomes that are derived from a decision tree are mutually exclusive and represent collectively exhaustive outcomes. That is to say, no other possible outcomes exist other than those presented in the decision tree.[126] This enables the time element and sequential nature of mitigation decisions to be graphically represented, adding further insight into the nature of decision about hazard mitigation for hospitals. Much like the use of influence diagrams, decision trees presented herein do not include statistical probabilities that would enable one to calculate the expected utility of decisions. Instead, the outcomes are colour-coded to graphically represent decision paths that lead to outcomes that are more likely to meet the 'direction of preferences' of most decision-makers in this context. By 'direction of preferences' it is meant that in general, all decision-makers prefer less risk to more if all other factors are equal. Of course, other factors are not equal, and decisions involve choices that reflect difficult trade-offs. However, rather than define an appropriate decision path, decision trees as used here depict the trade-offs and enable decision-makers to envision the steps and choices that need to be made to reach their own preferred outcome. Again, this reflects the variation in priorities of each of the case studies included in this thesis.

2.8 Summary

Sustainable disaster mitigation is an essential component of the broader agenda of urban sustainability. The literature challenges planners to see disasters as predictable outcomes of unconscious or conscious choices, to alter the focus of disaster planning from narrow conceptions of risk to broader understanding that places the focus on vulnerability. However, one of the challenges of the literature is to place local community decision-making processes into the context of disaster resilience.

One consequence of the fragmented approach to disaster mitigation planning is the lack of comprehensive data on the impacts of disasters on healthcare facilities. Without an improved understanding of the impacts of power

[126] Clemen, Robert T. and Terence Reilly. 2001 p. 70

and water outages on hospitals, it is difficult to understand what efforts are needed to reduce the impact of these outages on society. Yet, hospital emergency planners, those working on these issues on a daily basis, armed with intimate knowledge of their facilities, offer a wealth of largely untapped knowledge that ought to be applied systematically.

Once collected, the site-specific knowledge of individual planners can be used to characterize the decision environment of disaster mitigation planning for hospitals. By doing so, it may be possible to better understand the decision-points where different choices have the greatest likelihood of creating safer, more sustainable communities through disaster resilient hospitals.

Chapter Three: Method and Data

3.1 Overview of Research Strategy

The essence of the research method of this thesis is to review the literature, seek expert opinion and knowledge from emergency practitioners at several facilities in three cities, and then apply tools of decision-analysis to analyze the data. Only by combining these approaches can the research questions posed by the thesis be addressed adequately.

One of the key questions is to document the impact of power and water outages on hospital service and capacity. An obvious starting point has been to review the literature regarding the effects of water and power outages on North American hospitals. This has enabled a basic understanding of many of the key issues and risks facing hospitals and also contextualizes the regulatory environment of hospital emergency preparedness. Moreover, the literature review assisted in identifying relevant interview candidates and facilitated more in-depth interviews with emergency planning professionals. Yet, the literature on the impacts of power and water outages suffers from several major limitations. First, it does not provide a comprehensive overview of the frequency and duration of power/water outages on hospitals. Most power outages occur on a local level and do not attract the attention of large media organizations or academics working on these issues. Additionally, the American Hospital Association does not maintain a database of power and water outages.[127] Consequently, the data is fragmented which makes it difficult to understand the full extent and consequences of power and water outages on hospitals.

Another component of the literature review has been to identify potential performance measures from which to assess, compare, and report on the impacts of power and water outages. Some performance measures that have emerged from this study include: deaths, casualties, financial performance, bed occupancy rates, and staffing levels. However, in order to better understand how

[127] Personal Communication, Kim Garber, Information Specialist, American Hospital Association Resource Center, September 7, 2005

hospitals are impacted by power and water outages other measures will be needed. Information pertaining to what types of data are available, and the accessibility of that data, is a critical contribution of the interviewees. The contribution of the interviewees to the content of this study has been immeasurable. Persons selected are generally facility managers, emergency planners, government officials, academics and two physicians.

Once the impacts are better understood and characterized, the research aimed to address how these impacts can be mitigated. Here, the focus for answering this question lies on the experience of the emergency planners in each of the three case study areas. While planners in Vancouver and Los Angeles have not had to deal with a major disaster in recent memory, the 1999 Chi-chi earthquake in Taiwan is a more recent event that illustrates concrete examples of successful and unsuccessful mitigation efforts, both ex-ante and ex-post disaster.

The Taiwan case study benefits this project by providing real-world experience in managing widespread and extended lifeline infrastructure failures that occurred after the 1999 Chi-chi earthquake. It illustrates the consequences of power and water outages in a modern hospital in a level of detail not available in the literature. The event impacted hospitals in two general ways, in the first, it knocked out power and water to hospitals completely, while other hospitals' back-up power generators did function, and these facilities were called to rely on back-up power for a period of 4-7 days.

The Vancouver case study was selected because of its location in a region with a significant seismic risk but no recent experience in dealing with a significant lifeline infrastructure failure. Moreover, the case study hospital, Providence St. Paul's (SPH), was chosen because of the age of the facility and the significant challenges to disaster mitigation older structures pose.

Finally, Los Angeles was selected as part of this study in order to understand how hospitals in one of the most seismically prepared regions in the world are preparing for disaster. Moreover, Los Angeles area hospitals were affected by lifeline outages during the Northridge earthquake that illustrate how mitigation strategies evolved after this event.

Additionally, to move beyond current disaster mitigation planning, emergency professionals were asked questions such as "If there were not constraints, what would a comprehensive emergency preparedness plan for power and water outages consist of?" This type of question may illustrate financial barriers, but also other barriers such as regulatory constraints or organization preferences. It also assists to clarifying the dimensions of risk that decision makers are incorporating in their decision-making process. That is to say, by understanding the dimensionality of the risk issue as understood by the decision-maker, it may become possible to identify how decisions about risk mitigation in hospitals are affected by how the problem is framed and understood by decision-makers.[128]

Last, decision analysis techniques will be applied in the analysis of the information in order to gain insight into where new opportunities for sustainable hazard mitigation in healthcare can be achieved.

3.2 Case Studies

The aim of the project is to assess the impacts of water and power outages on hospital service and capacity. The nature of the event causing a critical failure in lifeline services ranges from a technical failure at the site level, to broader citywide or regional outages and up to external events such as a natural disaster crippling the infrastructure services both within and without the immediate hospital facilities. This results in two very different scenarios for assessing the performance of hospital services during the infrastructure failure. Thus, the first stage of the research process has been to establish the likelihood, magnitude and duration of infrastructure failures through a review of the relevant literature. After establishing the vulnerability of hospitals in general, and understanding specific consequences that have occurred in the past. This overview revealed that little is known in the literature about the precise impacts of

[128] Fischhoff, Baruch et al "Defining Risk" in Readings in Risk Theodore Glickman and Michael Gough (eds.) Resources for the Future, Washington, D.C., 1990.

water and power outages on hospital service and capacity over a duration that is possible under the scenarios of infrastructure failure deemed most likely. A case study methodology was adopted in order to answer how a power/water outage would affect hospital services. Three regions were selected on the basis of their historical experience in dealing with major infrastructure failures and their state of planning and preparation for dealing with these events. Three hospitals were researched in the Taiwan case study, one in Vancouver, and two in Los Angeles. The selection was based on the willingness of acute care hospitals in each of the case study regions to become involved with the project, share data, and participate in interviews.

Thus, by selecting these case studies a thorough analysis is made possible because they reflect actual, first-person experience with long-term power and water outages, represent institutions fulfilling a similar critical function within their communities, and reflect a range in preparation for dealing with a power and water outage. One of the critical differences amongst the three case studies is the legislative environment regarding emergency preparedness standards. While the different standards make direct comparison difficult, they also provide insight into how decision-making responds to different legislative environments.

3.3 Interviews

In total, twenty-one interviews were conducted with emergency preparedness planners, facility engineers, academics, medical staff, and government officials. Table Two provides a more detailed summary of the participants in the study. Most of the interviews were conducted in person after contacting hospitals after outlining the objectives of the project. In many cases, interviewees offered brief tours of their facility and highlighted developments and emergency preparedness equipment such as EPSS, emergency medical equipment storage, and back-up communications systems. These tours offered greater clarity and insight garnered from the interview responses and discussion. Many of the hospitals that participated in the study also supplied internal documents that summarize their emergency planning, vulnerability analysis, or summaries of previous experiences with disasters. These documents, while not private, are difficult to locate and proved valuable in the study. While all participants were asked all of the questions in the sample script, variations frequently occurred in order to clarify, expand, or contextualize answers provided. Each of the hospitals involved have a different level of experience with disasters and different levels of preparation; follow-up interview questions naturally reflected this diversity and developed themes that emerged from that facility and individual's experience.

Table Two: Expert Interview: Number and Roles of Participants

		Taiwan	**Vancouver**	**Los Angeles**
Site Level	Emergency Planner	5	1	2
	Facilities Engineer	0	1	1
	Medical Personnel	4	2	0
Regional Level	Public Health Authority	1	1	0
Technical Expertise	Academics	2	0	0
	Technical Consultants	0	1	0
Total:		12	6	3

Once the case study hospitals were identified, it became critical to identify those individuals within the hospital's administration who would be most qualified to shed light on the goals of the research question. First, as hospitals are complex systems, it was important to identify individuals with expertise in different aspects of the problem. Generally, building engineers-facility managers were an excellent starting point to understanding the extent and capacity of the hospitals emergency power and water systems. Next, in order to measure actual (in Taiwan) or potential impacts on patients, individuals with expertise and knowledge of the hospital's essential services such as the Emergency Department, Radiology, Pharmacy were asked to assess what the likely outcomes of a sustained power and water loss would be on their facility. These questions were two fold, the first instance assumed operations under expected emergency capacity conditions (back-ups operating), while the second instance asked for an assessment of how the hospital might function under total power and water outage scenarios. The available literature also played a critical role in determining the importance and scope of the interviews. For example, the Los Angeles seismic threat is well documented and substantial insight about the regional issues related to emergency preparedness could be gleaned from the literature. On the other hand, little is written about emergency preparedness in Vancouver, and therefore more reliance was placed on interviews. For the Taiwan case study, there is a great deal of English-language literature related to the short-term impact and aftermath of the Chi-Chi earthquakes, but few follow-up studies. For this case study, face-to-face interviews were critical in gaining a deeper understanding of the medium term impacts and responses to the Chi-Chi earthquake. Most interviews were completed using the following script. Minor alterations occurred due to follow-up questions to clarify or expand on responses made to the initial question.

Sample Interview Script

1. Has your facility previously experienced unanticipated electric power or water outages, from an earthquake or any other cause?

2. If so, please describe these events.

a. When did they occur?

What was the duration of the outage?

b. How many staff did not report for work/left early due to the emergency?

3. How did your facility cope with the loss of power or water?
   a. What impact did the loss have on your hospital's ability to perform its functions?
   b. Which departments are most seriously impacted?
   c. How is this impact measured and recorded?

      How did this impact patient care?

4. What did you learn from these events?
   a. How did the experiences change disaster preparedness at your facility, if at all?
   b. Are there any reports on these incidents that we could get copies of?

5. What was/would be the impact of a disruption of potable water?

6. What are your major concerns in terms of the reliability of water and power supply?
   a. How is this being addressed?

7. Who is involved in pre-event emergency preparedness at your institution?
   a. How is your hospital's mitigation program funded?
   b. Is it part of annual budget decisions?

A wide-range of input was sought to develop the information contained in this study. Unfortunately, several barriers presented challenges that could not be fully overcome. First, many individuals were simply too busy to meet for an interview. This was particularly problematic in terms of meeting with emergency medical professionals who are most directly aware of how power and water outages would impact treatment capacity. Second, personnel changes made others reluctant to participate; in several potential case study hospitals, emergency planners were new to their position and did not feel qualified to participate in the study. Once interviews were secured, participants were informed about the nature of the project, the potential uses of the information and publication, and asked for their consent to participate in the project. Most interviews were recorded electronically with permission of the interviewee. Copies of these recordings have been stored in compliance with the University of British Columbia's Behavioural Research Ethics Board approval granted for this thesis. As noted, a vast majority of interviews were conducted in person at the interviewee's place of employment. Most interviews in Taiwan were conducted in Mandarin Chinese, a second-language for the author.

3.4 Measuring the Impact of Power and Water Outages

Developing meaningful indicators to measure both the impact of power and water outages on hospitals and the success of mitigation measures has proven to be an elusive target for disaster researchers and hospital officials alike. So much so that in its 2003 report, the Canadian Hospital Accreditation Report made urgent recommendations to 21% of participating institutions to improve governance at their facilities. Of the recommendations concerning governance, fully 39% addressed issues surrounding evaluation, calling for the use of indicators.[129] While a lack of indicators is itself an indication of shortcomings within a decision context, indicators in and of themselves will not contribute to an improved decision process.

[129] Canadian Council on Health Services Accreditation 2004. p. 29

Seligson et al demonstrated that holistic performance measures are critical to evaluating and improving the performance of hospitals during emergencies; these measures should consider structural, nonstructural and content damage.[130] Thus, the indicators used to measure the impact of power and water outages assume explicitly a safe structure and need only focus on the consequences of power and water failure. By doing so, it becomes possible to not only isolate the effects of power and water outages on hospitals, but also to better understand the complex interaction between structural damage and loss of capacity due to power and water failure. This would enable decision-makers to better effectively prioritize mitigation activities. For example, if one invested in ensuring structural integrity, but did not ensure reliable power and water, the net result might be very little improvement in hospital capacity during an emergency.

In order to create good indicators, several factors must be considered. First, the goals of the decision and the objectives will indicate a directional preference of the decision context. For instance, in the case at hand, one would prefer greater safety instead of less, and lower costs rather than higher. Next, criteria need to be established, against which alternatives can be ranked in order of preference. Common criteria include cost, benefit, risk, legality, uncertainty, equity and timing to name only a few. While these attributes would be part of almost any decision process, it is important for decision-makers to add criteria that will capture important values that may be unique to a particular decision context. Measures, the focus of this section, are key to operationalize the criteria, creating the consistency that is essential to compare alternatives and make informed choices. According to Carl Patton and David Sawicki, good measures ought to be "tangible, if not quantitative, operational definitions of criteria."[131]

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[130] Seligson, Hope, Shoaf, Kimberley and Shinozuka, Masanobu "Multi-Hazard Modeling of Medical System Performance" ABS Consulting
[131] Patton, Carl and David Sawicki, Basic Methods of Policy Analysis and Planning Second Edition, Prentice Hall, New Jersey, 1993

3.5 Influence Diagrams and Decision Analysis

After the impacts of power and water outages are understood, the research attempts to characterize the decision-making context of mitigation decisions. While many analytical techniques such as benefit-cost analysis have been applied to disaster mitigation problems, this research will instead focus on structuring the decision-making process to understand and identify decision points where better choices might lead to better outcomes; better outcomes meaning outcomes that produce sustainable reduction in vulnerability of hospitals to power and water outages. Figure Four is an influence diagram that represents the general nature of decision-making relating to disaster mitigation and how decisions, and random variables affect the operational capacity of a hospital. This diagram will be developed in more detail in subsequent chapters.

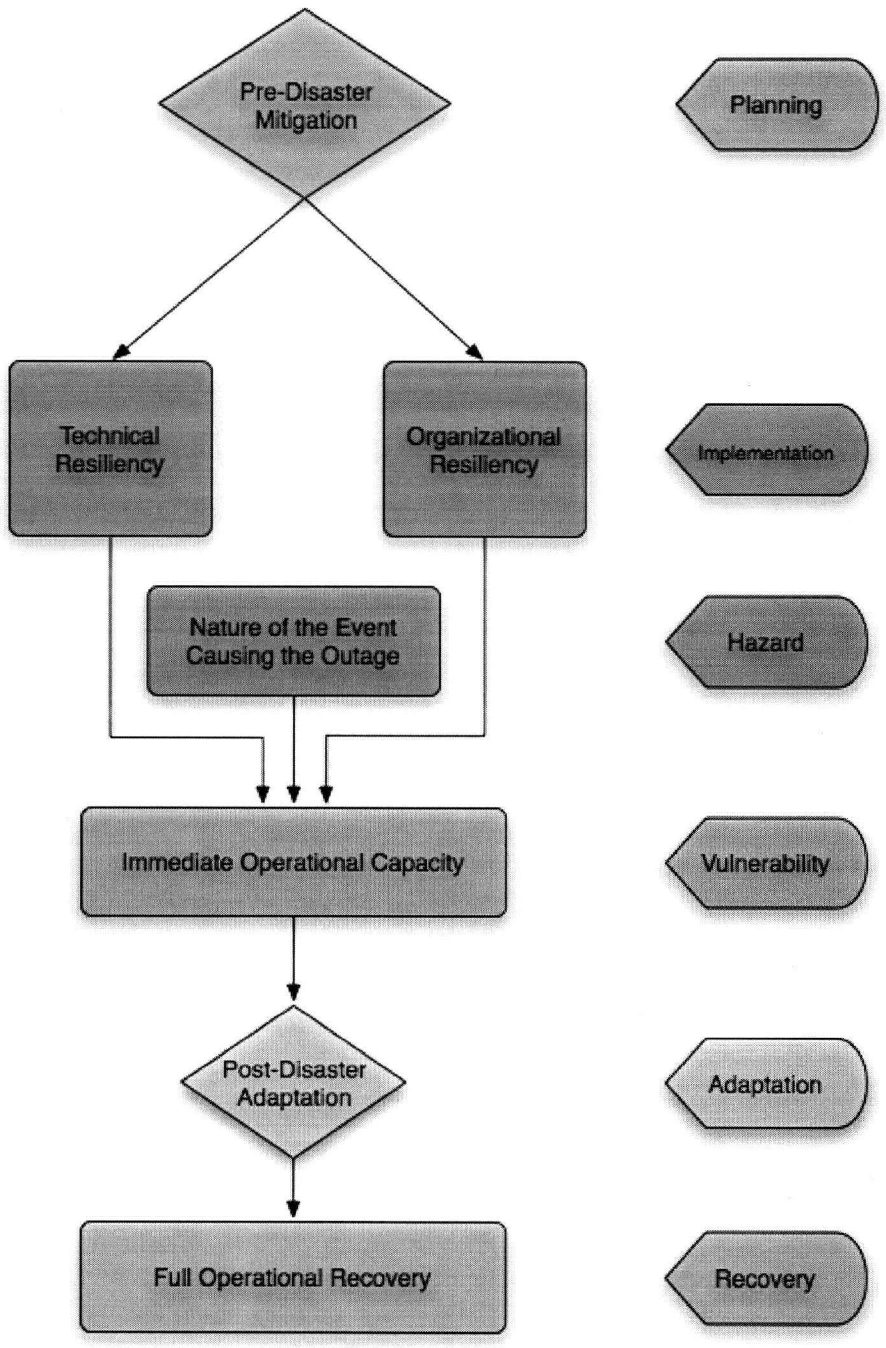
The diagram begins with decisions made about disaster mitigation and planning. These decisions include a number of decisions such as choices about capacity and design standards of EPSS, battery back up and equipment, inventory policies, personnel levels and training to name only a few. These choices lead to two distinct types of resilience: technical resilience and organization resilience.[132] Technical resilience refers to the ability of the hospital to maintain essential technical services such as building integrity, power and water. Organization resiliency refers to the ability of the hospital to maintain staff levels during an emergency and its ability to adjust to changes in demand and capacity. These elements of decision making are depicted with rounded-edge boxes indicating these levels are a random variable, influenced, but not determined by, decisions made about mitigation. The outcomes of these random variables influence the hospitals immediate operational capacity and its ability to respond to the emergency.

The nature of the event causing the outage is a random variable that will also have a serious impact on immediate capacity of the hospital. Once the disaster occurs, decision-makers will face a new set of choices that will impact

[132] Bruneau, M., Chang, S.E., Eguchi, R.T., Lee, G.C., O'Rourke, T.D. Reinhorn, A.M., Shinozuka, M., Tierney, K., Wallace,W.A. and von Winterfeldt, D. A Frameworkd to Quantitatively Assess and Enhance the Seismic Reslilence of Communities, Earthquake Spectra, 2003.

the hospital's ability to recover from the emergency. The choices available to decision-makers will be contingent on pre-disaster planning, mitigation, and the impact of the event causing the outage on the facility. Last, the ability of the hospital to recover from the disaster is reflected in the time it requires to regain full operational recovery.

Figure Four: Influence Diagram Schematic



Chapter Four: Case Studies

4.1 Lessons Learned: 1999 Chi-Chi Earthquake, Taiwan

The purpose of including a case study of the 1999 Chi-Chi earthquake's impact on hospitals is two-fold. First, the disaster illustrates many of the effects for which hospital planners need prepare. As noted above, sustainable disaster mitigation will benefit from learning about the experiences of others and incorporating the lessons learned in other regions. Second, because the impact of the Chi-chi earthquake was devastating to the healthcare system in large areas of Taiwan, it provides an illustrative example of adaptation and ex-post decision-making opportunities to mitigate the impacts of the disaster on the healthcare system. The following review is not a comprehensive report about the impacts of Chi-chi on Taiwan, rather it focuses on selected cases studies. The information is based on academic and government reports about the disaster and first-hand interviews conducted with representatives of the government, hospital officials, and emergency physicians working in Taiwan at the time the disaster struck.

The 1999 Chi-Chi Earthquake struck central Taiwan during the early morning hours of September 21, 1999 (magnitude 7.6). The shallow depth and alluvial soils in many of the affected areas made for extreme ground motion that exceeded 1.0g with strong shaking lasting over thirty seconds. According to Hsu et al (2002), the seismic moment of the Chi-chi quake, a measure of the total energy released by an earthquake, exceeded that of the 1995 Great Hanshin Earthquake in Kobe by a factor of ten.[133]

The event was a surprise to geologists both in terms of its location and magnitude, consequently exceeding the magnitude of the region's Maximum Probable Earthquake (MPE) upon which seismic building design codes are

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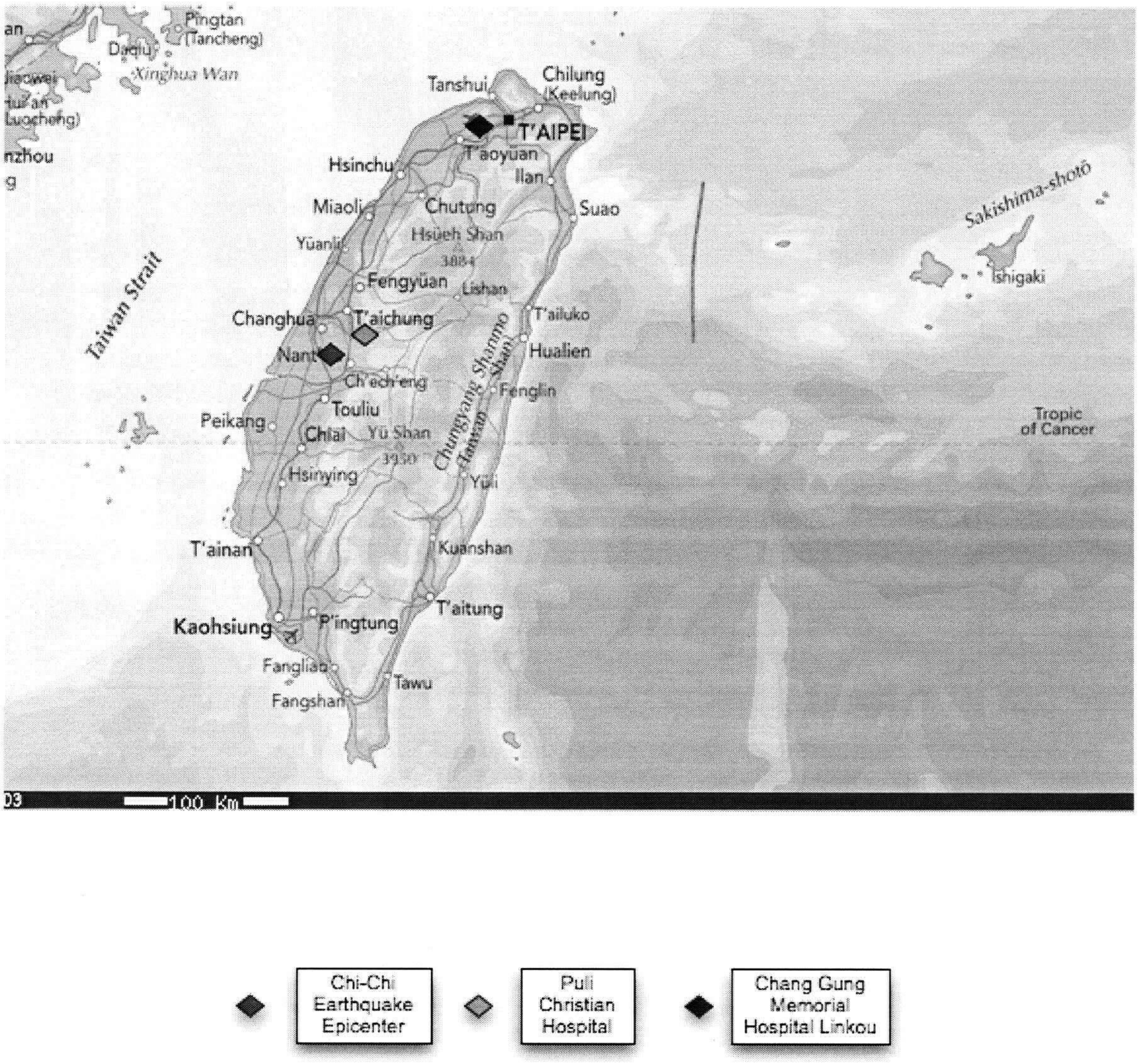
[133] Hsu, Edbert, Matthew Ma, Fang Yue Lin, Michael J. VanRooyen and Frederick M. Burkle Jr. "Emergency Medical Assistance Team Response following Taiwan Chi-chi Earthquake" in *Prehospital and Disaster Medicine* January-March 2002 http://pdm.medicine.wisc.edu

based.[134] The earthquake occurred along the Chelungpu fault in Nantou County, directly impacting that county and adjacent Taichung County and Taichung City. Nantou County is a relatively sparsely populated, mountainous region in Central Taiwan, home to approximately 500 000 people living in eight towns, four townships and numerous village and rural settlements.[135] The earthquake resulted in the deaths of 2 415 people and injured another 23 984. In total, over two million people located in Nantou and Taichung counties were directly affected by severe ground shaking, while substantial ground shaking and building collapses occurred 136km north in the capital, Taipei. The earthquake destroyed 48 000 structures, and caused another 40 314 to partially collapsed. There were 4 375 healthcare facilities within the six counties most seriously effected by the earthquake, of which 165 are hospitals.[136]

[134] Lin, Cheng-Horing "A Major Earthquake in the Strong Crust: The 1999 Chi-chi Earthquake" in *Western Pacific Earth Sciences Vol. 1 No. 3* August, 2001 p. 339-350
[135] Nantou County Government, "Introduction to Nantou" http://www.nantou.gov.tw/english/main.htm
[136] Tsu, T. Soong, Yao, George C. and C.C. Lin "Damage to Critical Facilities Following the 921 Chi-Chi, Taiwan Earthquake" 2001 Available online at: http://mceer.buffalo.edu/publications/resaccom/00-SP01/Chapter3.pdf

Figure Five: Taiwan Disaster Area and Case Studies*



Source: Original Map http://uk.multimap.com/index/TW1.htm Modified by author.

While frequently labeled as the "disaster of the century" by the popular media, it is worth noting that the Chi-chi earthquake ranks as only the third worst disaster of the century measured in terms of the numbers of deaths in Taiwan.[137] This is not to in any way minimize the catastrophic and severe impacts the

[137] EM-DAT: The OFDA/CRED International Disaster Database, Université Catholique de Louvain, Brussels, Belgium http://www.cred.be/emdat/intro.htm Access time: 05/01/2005

disaster had on millions of people; it is simply to highlight the need for ongoing preparation for inevitable, future disasters.

Immediately after the temblor, 80% of the region's 5 million residents were without water, and most of the island was without power. The Shihkang Water reservoir that supplied 1.1 million residents of Taichung and Chang-hua with water was destroyed when the Shihkang Dam failed, but rapid repair efforts reestablished drinking water supply within four days.[138] The quake also knocked off 90% of the entire island's electricity supply.[139] While no damage to nuclear power plants were incurred, two of the island three nuclear plants were shut-down as a precaution because of fluctuations in the electrical grid that were caused by the failure of the Chungliao power station in Nantou county, 5km from the quake's epicentre. The Chungliao power station was a critical linkage in Taiwan's electricity distribution network because it moved surplus power produced in the south to the island's more populous and industrial north. The isolated location of the station and the destruction of access roads to the facility also complicated repair efforts, further delaying power restoration.[140]

In the wake of the disaster and ensuing ten days of rolling power outages, Taipower, the state-run utility has launched a project to increase redundancy in its transmission system to reduce this type of vulnerability by 2007.[141] This severely exacerbated the lack of electrical power in Taiwan, as it took a week to bring the nuclear power stations back online. Furthermore, hydroelectric power stations, while not a major source of electrical power in Taiwan, were offline for ten days after the earthquake.

[138] EQE Consulting "Chichi, Taiwan Earthquake of September 21, 1999 (M7.6) Available online at: http://www.absconsulting.com/resources/Catastrophe_Reports/Chichi-Taiwan-1999.pdf
[139] Japan-Hong Kong Joint Reconnaissance Team "Taiwan Jiji Earthquake September 30 to October 5, 1999
[140] Ministry of Interior "[illegible]" (Taiwan Disaster Report) 2002 (in Chinese) http://www.moi.gov.tw/stat/topic/topic148.htm
[141] Taipower "The Fifth Distribution Projects" 2003, Available online at: http://www.taipower.com.tw/~d105/eng/Fifth_Distribution.htm

Overview of Taiwan's Healthcare System

Since 1995, Taiwan has maintained a National Health Insurance (NHI) program that is mandatory for all citizens. The system incorporates private and public hospital facilities and is paid through government contributions, mandatory salary deductions, and nominal user fees that are paid at the time of treatment. The system operates 133 398 beds, 69% of which are offered by private hospitals, and represents approximately 59.63 hospital beds per 100 000 people.[142] Of note, of the 994 hospitals in Taiwan, as of 2002, only 529 had successfully been accredited to operate as a hospital facility.[143]

Due in part to lessons learned during the 1999 quake, Taiwan has been implementing a 5-year plan designed to improve emergency care in Taiwan. The program features increased governmental supervision of key emergency medical facilities, improved physician training, and financial subsidies to improve emergency room facilities. Perhaps of greatest import for managing the immediate post-disaster impacts, the plan has invested in an interdepartmental operational network that links central and local emergency units. The network works over the internet, and provides real-time data about ED department status, ICU beds available, and hospital beds available. While potentially an important and effective communications resource, the system has not been tested during an emergency of the magnitude of the Chi-chi earthquake and it remains to be seen if a power and infrastructure dependent communications network will operate during an emergency.[144] Another initiative of the plan was to formalize national and regional disaster medicine teams that could play a pivotal role in managing and triaging incoming patients to medical facilities in future disasters.

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[142] Government Information Office, "Taiwan Yearbook 2004" 2004 Available online at: http://www.gio.gov.tw/taiwan-website/5-gp/yearbook/P243.htm#1

[143] Government Information Office, 2004 http://www.gio.gov.tw/taiwan-website/5-gp/yearbook/P243.htm#1

[144] S.T.Chang, Facilities Manager and Emergency Planning, Chang-Gung Memorial Hospital Linkou, Interview by Darren Cole, July 12, 2005

Impact of Earthquake on Healthcare Facilities

In the immediate aftermath of the quake, thousands of hospital beds were lost due to structural and non-structural damage to hospitals located near the quake's epicentre. Given the severity of the earthquake, the age and design of the structures, and proximity to the epicentre it is not surprising that some hospital facilities failed in their entirety. These buildings were rendered useless for the duration of the disaster, and required reconstruction or major repair in the months and years following the earthquake. However, a significant number of hospital beds were lost because of non-structural damage to hospital facilities. The most common non-structural damages included: fallen interior walls and ceilings, toppling, sliding, or collision of medical and non-medical equipment, overturning of water and oxygen tanks, interruption of emergency power, and flooding due to pipe breakage.[145] In fact, according to personal communication with Professor George Yao of Tainan's Chang Kung National Univeristy, no hospitals in the immediate disaster area had functioning emergency power after the earthquake.[146] Although officials acted quickly and were successful in delivering power to hospitals outside of the immediate disaster area, power outages in the disaster area were widespread and prolonged. According to the Taiwan Ministry of Health survey conducted five days after the earthquake, only 25% of residents in Nantou and Taichung counties had electrical power, a full five days after the event.[147]

Not only was the capacity of hospitals severely curtailed in the disaster region, but there was a corresponding upsurge in demand for care, compounded by a number of factors that were also identified in the aftermath of the 1999 Izmit

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[145] T. Soong, George C. Yao and C. C. Lin MCEER, 2000 Available online at: http://mceer.buffalo.edu/publications/resaccom/00-SP01/Chapter3.pdf

[146] Professor George Yao, Interview, May 23, 2005

[147] Chen, Kow-Tong, Wei Chen, Josephine Malilay and Sing-Jer Twu "The Public Health Response to the Chi-Chi Earthquake in Taiwan, 1999" in *Public Health Reports* November-December 2003, Volume 118

earthquake in Turkey. The most significant problems faced by hospitals after the earthquake were:[148]

1) excessive patient load;
2) inadequate medical records;
3) inadequate communication;
4) inadequate critical care beds,
5) inadequate numbers of experienced personnel,
6) unnecessary crowd of persons in the emergency department

Clearly, the problems faced by hospitals in the aftermath are acute manifestations of challenges hospitals normally face. This establishes the basis of incorporating disaster mitigation planning into the broader planning process of the hospital. In fact, post-disaster experience and adaptation may provide insight in how hospitals can better deploy their resources to meet these challenges. Hospitals must not only prepare for a surge of injured patients in need of medical care arriving at their facilities, but also for the influx of the 'worried well.' In one study after the 1999 Chi-Chi earthquake in Taiwan, researchers found that in one township 47% of the local population sought medical treatment even though only 4% of the population was injured.[149] Similar demand for medical care in large urban centres could cripple even the most-prepared facilities if plans are not made to respond to this demand.

4.2 Taiwan Case Study: Puli Christian Hospital, Puli, Taiwan

The Puli Christian Hospital (PCH)is located in the township of Puli, Nantou County. Puli is a regional town with a population of approximately 90 000 located at the gateway to one of Taiwan's most important tourist regions, Sun Moon Lake.

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[148] Engyndenyz,; M. Bulut, MD; H. Özgüç, MD; R. Tokyay, MD "The 24 Hour, Post-Earthquake Experience of a University Hospital in Turkey" in Prehospital Disaster Medicine 2000, 15(3):s76 Available online at: http://pdm.medicine.wisc.edu/Engyndenyza.htm

[149] Chou, Frank Huang-Chih, Tom Tung-Ping Su, Wen-Chen Ou Yang, Ming-kun Lu, and I-Chia Chien "Survey of Psychiatric Disorders in a Taiwanese Village Population Six Months After a Major Earthquake" in Journal of Formosa Medical Annex, Volume 104, No. 5 2000 p. 309

The city is connected to Taichung City by a 4-lane road that winds along the Wu River, rising from the Western lowland plains to the foothills of Taiwan's central mountains. The facility is located closed to the epicenter in neighbouring Chi-chi and consequently suffered severe damage in the wake of the earthquake.

The Christian Hospital in Puli is a powerful example of how non-structural damages can cripple even a well-constructed hospital. The main building of the 400-bed facility was about one year old at the time of the earthquake and survived the quake with only minor structural damage. However, officials were forced to evacuate the facility due to problems relating to water damage and equipment damage. Thus, during the 72 hours after the quake when capacity was most needed, the Christian Hospital in Puli was reduced to 10% of its original capacity.[150] The hospital was subsequently reoccupied, but required evacuation again after the 9/27 M6.8 aftershock. Undoubtedly, the confusion generated, and personnel required to move patients out of the hospital and into tents, and then back again, added to the burden and fatigue faced by healthcare workers at the Christian Hospital. Moreover, as noted by Professor Yao, the lack of an earthquake emergency management plan made a difficult situation worse.[151]

Before considering the impact of 9/21 on PCH, it is important to consider several factors that make 9/21 unique. First, although the earthquake was centered over 100km away from Taipei, decision-makers such as the President and Cabinet members were awakened by shaking. The extent of the ground motion made it plain that this was no ordinary earthquake and even before knowing the location of the event, an emergency Cabinet meeting was convened within an hour to begin planning the emergency response. Indeed, the Chi-Chi earthquake created a Modified Mercalli VIII intensity in Puli and Modified Mercalli intensity of VII in Taipei City.[152] Unlike the Kobe experience in 1995, key decision-makers were acutely aware of the extent of the disaster and quickly

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[150] T. Soong, George C. Yao and C. C. Lin MCEER, 2000 and interview with Professor George Yao, May 23, 2005.
[151] T. Soong, George C. Yao and C. C. Lin MCEER, 2000
[152] Munich Reinsurance Company "Schaden Speigal: Losses and Prevention" 44th Year, 2001, No. 1 Available online at: http://www.munichre.com/publications/302-02903_en.pdf?rdm=17147

mobilized emergency resources to respond. Prior to 9/21, the government did not have an earthquake emergency response plan in place, but using existing military command and control infrastructure, was able to coordinate a response that although flawed, was largely viewed as effective. Second, respondents consistently identified the relatively small size of Taiwan as a key factor in the effectiveness of the post-emergency response. In many communities and hospitals, such as PCH, road access was completely cut-off, making helicopters the only viable mode of transportation and rescue. Undoubtedly, the short distance of rescue flights effectively increased the airlift capacity and saved lives.

Soong, Yao and Lin reported on the immediate impact on PCH in the MCEER Reconnaissance Report published in April 2000. The major impacts reported were as follows:

- A major part of the hospital was non-serviceable primarily due to nonstructural damage.
- Drastically reduced capacity (10% of original) at a time when demand was the highest.
- Trauma to patients through two relocations.
- Drastically reduced services due to equipment damage.
- The lack of an earthquake management plan probably made the situation worse.

This assessment was confirmed in interviews with Taiwan academics familiar with PCH, and through interviews with hospital officials including Joyce Mu, the Vice Director Department of Development, who was on-staff at the time of the disaster. Given the age of the facility, the drastic reduction of capacity is somewhat of a surprise. At the time of the disaster, the facility consisted of two-buildings with approximately 400-acute care beds. Building "A" was approximately twenty-five years at the time of the disaster, while building "B" was just over a year old. Prior to the earthquake, the facility did not have an emergency preparedness plan in place, which makes PCH an effective example of the potential for ex-post adaptation.

Figure Six: Puli Christian Hospital: "New Building (left) Building B (right)

Source: Author December 5, 2005

The earthquake struck in the early morning hours and immediately knocked out power and water to the facility. Building "A" suffered extensive damage and was later demolished. Building "B" suffered extensive damage to ceiling tiles, dislodged electrical cables, damage to equipment, and minor structural damage. Notably, even though Building "B" was safe to occupy from an engineering point of view, few of the staff and patients at the facility were willing to occupy the building. Thus, immediately after the earthquake, the hospital began evacuating patients to the parking lot in the cool and wet weather without shelter. This precaution was based on uncertainly and lack of situational awareness caused by an almost complete loss of communications. There was simply no way for staff onsite to assess the structural integrity of the facility, and the prudent course of action was to evacuate staff and patients.

Figure Seven: Nonstructural Damage to PCH Building B

Source:▯ ▯ ▯ ▯ ▯ ▯ ▯ ▯ ▯ ▯ ▯ 921 ▯ ▯ ▯ ▯ ▯ ▯ (Puli General Hospital 9/21 Earthquake Report

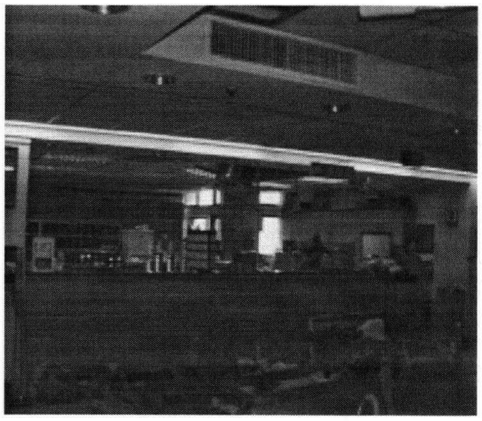
The first major issue affecting the hospital staff was the loss of communications. The earthquake knocked out landlines and mobile phones. The hospital's only mode of communication was via their HAM radio equipment. The operator literally scanned amateur radio frequencies looking for HAM users outside of the disaster zone who had access to communications to update emergency officials in Taipei and Taichung of the extent of the emerging disaster at the PCH. Onsite communications were maintained by the use of walkie-talkies, but there was no ability to contact staff or directly communicate with offsite emergency planning officials. Clearly, community members, hospital staff and volunteers coalesced in a new spirit of cooperation that so frequently fosters increased community resilience and cooperation.[153]

As a result of the disaster, all major surgeries, critically ill or injured patients, and chronically ill such as kidney dialysis patients were airlifted to hospitals in Taipei. The road connecting Puli to Taichung was impassable due to landslides, bridge failures and safety concerns related to several mountain tunnels. Thus, the capacity and demand management of the hospital was limited. The ability to evacuate was limited by the capacity of helicopters. In the early

[153] Tierney, et al Facing the Unexpected: Disaster Preparedness and Response in the United States Joseph Henry Press, Washington, D.C. 2001 p. 150

days, evacuation was based on emergency triage. Consequently, it was not always possible to evacuate patients and hospital personnel needed to provide care in extremely challenging conditions. The loss of transportation connections also made re-supplying the hospital difficult. This responsibility was quickly taken up by the military which used airlift and off-road transportation equipment to re-supply necessary medical supplies and equipment. However, in spite of these massive efforts to adapt, capacity at PCH was reduced by 90% during the critical first 72-hours after the disaster.

<u>Figure Eight: Exterior and Interior Damage to PCH Building B</u>



Source:□ □ □ □ □ □ □ □ □ □ □ □ 921 □ □ □ □ □ □ (Puli General Hospital 9/21 Earthquake Report

The hospital was without power and water for ten days. During the first day after the disaster, hospitals volunteers scoured local supermarkets for bottled water. Water tanker trucks were quickly brought in and hospital officials reported the supply of water was adequate using tanker trucks. The loss of water had little operational affect on the hospital because seriously ill patients were evacuated to other facilities within twenty-four hours of the emergency. Another fortunate aspect of the emergency was that the 9/21 earthquake did not trigger large fires. Hospital officials acknowledge that had the hospital faced large numbers of burn victims, the lack of potable water would have posed a serious threat to adequate care. Sanitation was maintained through the use of alcoholbased cleansers that do not require water. No major problems related to infection control were reported due to the loss of water.

In the wake of the outages, acute care was the most adversely affected area of the hospital. Effectively, the hospital's acute care facilities closed and patients were evacuated to other facilities. No major surgery could be performed and diagnostic capability was severely diminished. However, within 24 hours of the disaster occurring, the PCH began to restore capacity to its Emergency Department by constructing a temporary treatment facility in the parking lot adjacent to the hospital; during the first twenty-four hours after the disaster the hospital was able to treat 753 patients in an improvised, outdoor treatment setting. The data also reflect the impact that the loss, evacuation, occupation, and subsequent re-evacuation had on acute care at PCH. During the first forty-eight hours, there was no acute care treatment available. By September 23, limited acute care capacity had been established in the hospital parking lot, which increased to 439 by September 24. However, that capacity was lost almost immediately on Sept. 25 when the facility was re-evacuated due to aftershocks. It was not until a week after the disaster that acute care treatment in the damaged Building B was fully re-established. PCH defines acute care as treatment provided to in-patients, while emergency care is treatment provided to patients who are not formally admitted to the hospital. Table Two provides a breakdown of the number of patients treated during the first ten days after the earthquake.

Table Two: Post-Earthquake Healthcare Demand

Date	Acute Care	Emergency Care	Transferred Patients	Deceased Patients
9/21	-	753	70	58
9/22	-	302	69	14
9/23	83	166	75	10
9/24	439	388	12	6
9/25	192	385	5	4

9/26	283	339	16	3
9/27	723	25	3	1
9/28	1578	88	2	2
9/29	1621	83	2	0
9/30	1653	68	4	0
Total	6572	2598	258	98

Source:▯ ▯ ▯ ▯ ▯ ▯ ▯ ▯ ▯ ▯ ▯ 921 ▯ ▯ ▯ ▯ ▯ ▯ (Puli General Hospital 9/21 Earthquake Report)

The exterior treatment centre was initially constructed by local volunteers and companies who sell portable tents typically used to host weddings and funerals. The tents provided some shelter for staff and patients, and importantly, enabled the hospital to move some equipment from within the abandoned hospital to the treatment area. Volunteers also arrived to help modify the hospital's EPSS system such that it could now power medical equipment and provide lighting to the tent hospital. Another ex-post adaptation was the construction of emergency toilet facilities. Remarkably, PCH, with no pre-established emergency response plan, had created a functional treatment centre.

While the tent hospital was a first step toward recovery, it was insufficient to meet the medical needs of its patients and protect staff and patients from the cool wet weather at the time. The government assisted by providing shipping containers that were transformed into a doctor's offices and rest areas, waiting rooms, laboratories, and patient examination and even ward rooms. As noted in the table above, the ability of PCH to offer advanced treatment was severely impaired; more than two hundred patients required medical airlift service to transfer them to hospitals in Linkou and Taipei. Due to the nature of the building stock in the Puli area, most of the serious injuries were crush injuries and head trauma. Fortunately, there were no major fires after the earthquake and 75% of patients who sought emergency care were treated for bruises and laceration that were considered minor to moderate.[154]

Figure Nine: Temporary Exterior Puli Christian Hospital

In the immediate aftermath of the disaster, 172 staff members returned to work throughout the emergency. Many staff were unable to work due to damage to their homes or damage to critical transportation infrastructure. Of particular importance, the sole road link to Taichung and, by extension, the rest of Taiwan, was cut-off for a week after the disaster. Once the road was restored, emergency relief medical crews from Taichung and Taipei area hospitals were transported to Puli to relieve the over-burdened staff. The lack of available staff on site during the emergency compounded the impact because staff were occupied solely with responding to the needs of patients. This made it extremely difficult to assess the damage to the facility. While damage to the structure was easy to report, assessing and reporting damage to the contents of the building department by department proved difficult. Other difficulties included tight medical supplies which could only be replenished through helicopter deliveries during the first after the disaster.

[154] Source:□ □ □ □ □ □ □ □ □ □ □ □ 921 □ □ □ □ □ □ (Puli General Hospital 9/21 Earthquake Report) 2000

Partially due to the uncertainty regarding the safety of the structure, the staff and patients of PCH endured two emergency evacuations: one on the night of September 21 after the earthquake, and again a week later on September 28 after a M6.8 magnitude aftershock. Evacuation not only required relocating patients, but also meant moving medical equipment and supplies back to the temporary hospital constructed in the parking lot. This caused great stress on patients and physical hardship on staff and volunteers at the facility. It was not until 10 days after the first temblor that the hospital re-occupied its main facility and began the recovery process.

Lessons Learned

In the wake of the hardship experienced at PCH, hospital officials embarked on major changes in response to lessons learned during the disaster. In terms of technical resiliency, the hospital has upgraded its EPSS capacity, and developed a more rigourous testing protocol to help ensure more reliable operation in future emergencies. The hospital has also upgraded nonstructural mitigation in "Building B" by restraining more equipment, cables and water pipes. However, due to the nature of the hospital's function, officials say that it is impossible to restrain all equipment in the facility simply because mobility of that equipment is essential for its normal use. PCH has continued to expand and, as of December 2005, was about to open a new building to replace the demolished "Building A." The new building includes the hospital's emergency department, ICU, and intensive care ward beds.

While the changes to its technical resiliency should improve PCH's resiliency to future disasters, hospital officials believe that the most substantial improvements to the hospitals disaster resiliency lie in changes intended to improve organizational resiliency at the hospital.

The hospital discovered that its staff performed well under the pressure of the immediate disaster. The daily demand of treating patients in temporary facilities taxed the ability of medical workers to adapt, but also gave them purpose. However, as time wore on, the combined stress of both living and working in a disaster zone proved to be extremely difficult for many staff members.

As noted, prior to the Chi-Chi quake, the hospital did not have an official emergency plan. Now, the hospital boasts a detailed plan that is practiced on department levels at various times throughout the year, and by the entire hospital on an annual basis. Part of the emergency plan includes a ranking system that reflects the seriousness of the emergency. For example, in a minor emergency, no immediate change in hospital staff is required, but all medical and non-medical personnel and notified and placed 'on-call' should their services be required. In a major emergency, all staff have pre-determined emergency responsibilities. For example, Ms Mu, who is a non-medical staff member, is responsible to ensure the safe evacuation of one section of the hospital. The intent of the plan is to ensure an orderly transition to emergency operations. To do this, medical staff have been given specific medical roles such as emergency triage while non-medical staff will assist in setting up mobile triage stations and alternative care sites.

PCH continues to develop their emergency drills to ensure realism and relevance to the types of emergencies they are likely to face. This type of training, along with the memories of Chi-Chi, help ensure that PCH is better prepared for future disasters. Six years after Chi-Chi the hospital has almost fully recovered from the disaster and is opening a memorial to those lost in the disaster and to reflect on the community spirit that emerged to support the hospital's recover. In this spirit of recover and re-birth, PCH has adopted a pictured of a baby born at the hospital the day of the earthquake as a symbol of hope and the resilience of the organization, and community, to recover from the disaster.

4.3 Taiwan Case Study: Chang-Gung Memorial Hospital, Linkou, Taiwan

Chang-Gung Memorial Hospital Linkou(CGMH-L) is the largest of the organization's seven hospitals in Taiwan, making the Chang-Gung hospitals Asia's largest private hospital organization. The hospitals have a combined total 6800 beds and serve 27 000 outpatients per day.[155]

CGMH-L is a 3400 bed facility with advanced care in all aspects of medical services including emergency department, organ transplant, renal care, pediatrics and long-term rehabilitation. CGHM-L is also the lead hospital in the Taoyuan Region Acute Care Delivery System (TRACS), and is also the primary emergency facility responsible for responding to any mass casualty events at nearby Chiang Kai Shek International Airport, Taiwan's main international airport.

Located approximately 110 km north of the epicentre the quake did not impact the structural integrity of the Linkou facility. However, like the rest of Taiwan, the hospital lost its external power and water supply because of the extensive power outages that swept the island after the earthquake. Emergency generators were automatically started within 8 seconds of the outage, supplying full power to the hospitals operating rooms, emergency department, ICU, and notably, elevators. The remainder of the facility was powered, albeit with demand reductions such as reduced lighting. According to S.T. Chang, all of the hospital's essential functions were fully operational and no patients were affected by the outage.

The hospital performed its function as a regional emergency treatment center well in the aftermath of the earthquake. With its emergency power supply functioning as designed, the hospital staff began to prepare for an influx of

[155] Chang-Gung Memorial Hospital website, Available online at: http://www.cgmh.org.tw/eng2002/about01.htm#03

injured patients. The Chi-chi earthquake happened at one in the morning, a time when the hospital is at its lowest staffing levels. For example, medical personnel are at minimums with little slack in personnel resources. Consider if the disaster were to occurred during the middle of the day. At this point, personnel dedicated to serving the thousands of outpatients each day, many of whom do not require immediate treatment could be shifted to emergency roles, thus substantially increasing the immediate capacity of the hospital to deal with the first surge of victims. Beyond the staffing limitations, emergency response at CGMH-Linkou was impaired by a lack of information regarding the severity of the event. While the ground shaking was strong, no obvious physical damage was sustained at the site. The only other indication of the potential severity of the event was the power outage that immediately accompanied the ground shaking. Mobile and land-based telecommunications systems were quickly rendered inoperable by the sudden surge of demand. Without information about the extent of the emergency, on-site hospital officials were initially uncertain about the extent of the disaster and consequently did not immediately begin preparations to respond to the emergency they now faced.

The Linkou facility maintains a 72-hour supply of fuel to supply the generators. The facility does not have contracts to re-supply fuel during an extended outage, but would instead rely on the government to provide necessary fuel. Another element of risk management at the Linkou facility was the decision to locate the backup generators on the roof, rather than within the facility or at ground level. This is an excellent example of how risk to essential emergency support systems can be reduced through effective pre-event hazard identification and appropriate design. While this facility has not flooded, other back-up generators have been destroyed by floodwater even in modern facilities such as Texas's Hermann Memorial Hospital.

Another important element of the design of the CGMH-Linkou site is that emergency water supplies are provided by on-site groundwater wells. Thus, the site does not require substantial on-site emergency water storage facilities, as long as it has electrical power, the site will have access to potable water. This also insulates the hospital from disruption to water supplies caused by the variability of water supplies in Northern Taiwan, which has experienced several municipal water outages due to both drought and excessive turbidity brought on my massive typhoon rainfalls. Several emergency planners have indicated the significance of access to groundwater supplies for dealing with vulnerability to water outages.

For one, without water, a hospital is crippled. Not only do most medical treatments require copious amounts of potable water, water is also an essential component in infection control and sanitation. If a region is facing extensive water outages, water borne illnesses such as dysentery will cause large numbers of patients to seek medical treatment. If the hospital is unable to maintain a sterile environment, it becomes a vector for the spread of the disease, rather than part of the solution.

4.4 Vancouver Case Study: St. Paul's Hospital

Decision-making in healthcare reflects the complex and fragmented environment of healthcare funding in Canada. However, many of the essential conditions of the Canadian healthcare system bear strong resemblance of those of Taiwan's, making a comparison possible. For example, like Taiwan, payments for healthcare services offered by hospitals are determined by government policy.

The Vancouver case study is based on St. Paul's hospital located in the west-end of downtown Vancouver. The facility offers leading care in a number of chronic and acute conditions such as renal and cardiac care, functions as a major trauma centre, provides a substantial portion of the region's available ICU and hospital beds (450 beds in total) operated by not-for-profit Providence Healthcare. At this time, the future of this facility is clouded as proposals for re-locating the hospital to a new facility located to the east on vacant lands near Terminal Station are under consideration. The local community has been engaged in an active effort to retain a full service hospital in the community. On the other hand, the hospital and province advocate construction on the new site to overcome many of the limitations of the existing site in terms of congestion, lack of expansion opportunities, and the need to incorporate new services and facilities. Undoubtedly this uncertainty surrounding the future role of the facility has impacted emergency preparedness decisions and potentially offers an opportunity to consider the trade-offs of retrofitting versus new construction to mitigate risks to healthcare facilities.

Risk mitigation of power and water outages in hospitals in Vancouver is of particular importance for a variety of reasons. First, the city is located in a seismically active region, a hazard that will be explored in more detail below. Of great significance however is the potential that the city could be cut-off from power and transportation infrastructures for extended periods of time in the aftermath of a major earthquake. Power is transported to Vancouver via transmission lines located in steep mountain valleys that are vulnerable to landslide risks in an earthquake, causing widespread damage in remote areas with poor access for repair crews. Transportation is highly dependent on a complex bridge network with uncertainty as to the performance of these structures during a large earthquake. Second, in addition to the seismic hazard, the region also experiences severe winter windstorms that may damage power distribution networks, again potentially requiring lengthy repair before service is restored. Last, the explosive growth in the region has increased demand without a concomitant increase in power generation and distribution, thereby increasing the strain on the system and the probability of a technical failure like the one that caused the 2003 Northeast blackout. Clearly, it is critical that hospitals function for at least 72-hours in the aftermath of a power outage if the emergency medical needs of the regions 2.5 million inhabitants are to be met.

According to the 2001 census, Vancouver's population stood at 545 671, a six percent increase over the previous 1996.[156] The city is quite densely

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[156] Statistics Canada "2001 Community Profiles" 2001 Available online at: http://www12.statcan.ca/english/profil01/Details/details1pop.cfm?SEARCH=BEGINS&PSGC=59&SGC=5915022&A=&LANG=E&Province=59&PlaceName=Vancouver&CSDNAME=Vancouver&CMA=&SEARCH=BEGINS&DataType=1&TypeNameE=City%20%2D%20Cit%E9&ID=1259

populated, with an average of 4 758 people per square kilometer located north of the north arm of the Mackenzie river, south of the Burrard Inlet to the north, and separated by a political boundary on its eastern edge. The city's location close to water and its density define one of its most significant vulnerabilities, its reliance on bridges for transportation and evacuation, meaning "communities in the region are vulnerable to damage and isolation during a large earthquake."[157] Other threats to the city include the fact that key infrastructure such as the Vancouver International Airport, major power distribution lines, and key bridges are located on lands widely considered vulnerable to liquefaction in an earthquake.

Emergency planning in the region has improved in recent years, prompted in part by a 1997 auditor general's report that condemned the lack of preparedness and planning to that point. In response to this report, the provincial government initiated a variety of programs aimed at reducing seismic risk, of particular important for our purposes here, substantial funds were directed to non-structural seismic retrofitting programs for hospitals. In spite of the promise of this program, and its almost certain cost-effectiveness should a large earthquake occur in the Lower Mainland, the program has been cancelled, and at this time, there are few funds available for seismic retrofitting of hospital facilities.[158] This cancelled program was run under the Seismic Mitigation Branch that operated from 1999-2003. According to a knowledgeable source close to the project, the project worked effectively because the hospital engineering staff possessed both the technical and site-specific knowledge to prioritize and implement non-structural mitigation projects designed to increase the resilience of power and water supplies in hospitals. The Auditor General's report also contained another important element of decision-making about mitigation budgets. The report argued that mitigation budgets ought to be separated from other budgets because monies made available for non-structural mitigation projects were all too often absorbed into the operational budgets of the

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[157] Clague, John "The Earthquake Threat in Southwestern British Columbia" Available online at: http://epe.lac-bac.gc.ca/100/200/301/ocipep-bpiepc/earthquake-e/clague.pdf

[158] Jay Lewis, Interview by Darren Cole

receiving institutions.[159] Even at the pace of mitigation achieved under direction of the Seismic Mitigation Branch, it is estimated it would have taken another ten to fifteen years to fully prepare Lower Mainland hospitals. In the wake of the program's cancellation, one expert estimates that hospitals in the region will probably have no functionality post-quake, limited functionality during the first week, and take some months before full functionality is restored.[160]

A cursory review of public comments made by public officials in the media indicates the uncertainty and lack of complete information surrounding seismic preparedness in Vancouver. For example, Bob Bugslag, executive director of PEP, quoted in Maclean's magazine notes that "Seismic upgrades of most major bridges and dams are in the final stage. . ."[161] Emergency planners and residents alike frequently misinterpret increasing the seismic performance of structures as meaning those structures are now "earthquake proof." However, Professor John Clague points out that even after the upgrades, they are "by no means earthquake proof; any significant damage to them would cripple the city."[162] Before turning to the decision-making environment of emergency preparedness in hospitals in Vancouver, it is important to note this widespread misconception that seismic upgrades eliminate seismic risk.

The seismicity of the region is only incompletely understood owing to an accurate seismic record that dates back only 130 years. Earth scientists are actively gathering geologic data to augment this understanding, but significant gaps and uncertainty remain. That said, the best estimates of earthquake recurrence in the region are reported in Table Three as follows:

[159] Jay Lewis, Interview by Darren Cole
[160] Jay Lewis, Interview by Darren Cole
[161] MacQueen, Ken "When B.C. gets hit" in *Maclean's Magazine* May 16, 2005 Available online at: http://www.macleans.ca/topstories/canada/article.jsp?content=20050516_105684_105684
[162] Clague, John "The Earthquake Threat in Southwestern British Columbia"

Table Three: Historical Seismicity in Southwestern British Columbia

Magnitude	Location	Return Period	Damage Area (km^2)*	Date of Last Event
8.9+	Subduction, Intersection of North American Plate, Juan De Fuca Plate	Approximately 500 years	100 000	1700
7.0	Intraplate, Southwestern BC or Northern Washington	30-40 years	20 000	June 23, 1946 (M 7.3)
6.0	Intraplate, Southwestern BC or Northern Washington	20 years	5000	April 29, 1965 (M6.5, under Seattle)
5.0	Intraplate, Southwestern BC or Northern Washington	5 years	1000	July 3, 1999

*Approximate values

Adapted from John Clague, Earthquake Risk in Southwester British Columbia

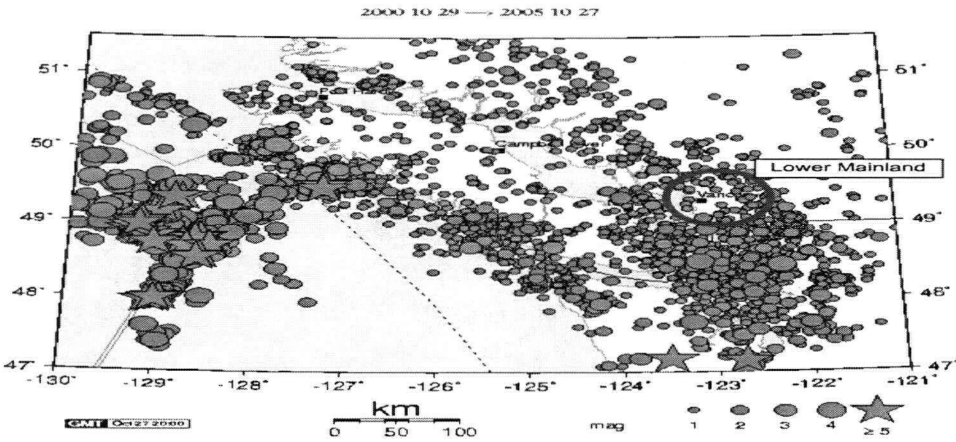
The data strongly indicate that another M7.0 earthquake is an event that will occur in Southwestern British Columbia, the only question remaining is when. The last earthquake of this magnitude occurred in 1946, which suggests two conclusions about the decision-making environment surrounding this potential event. First, a sense of urgency is necessary. While no on can predict when the quake will occur, the historical record of seismicity document by Professor Clague suggests the region is living on borrowed time. Second, demographic changes and human decision-making tendencies must be given serious consideration. Between 1946 and 1957, five magnitude 6-7 earthquakes occurred in the region.[163] However, there has not been a major earthquake since 1965. Additionally, since 1965, the region has experienced significant population growth with 700 000 people living in the region in 1946 compared to present day's 2.5 million plus. A significant portion of this population increase is due to migration from other parts of Canada and the Pacific Rim. Thus, the vast majority of residents living in Southwestern B.C. do not have direct experience of a large earthquake occurring in the region, and thus likely discount the possibility of one occurring in the near-term. Given the importance of the availability heuristic identified by Tversky and Kahneman in making decisions, this is likely a significant part of the explanation for the region's lack of preparedness in general, and hospitals in particular.

Figure Ten from Natural Resources Canada records seismic events over the past five years. Data that supports the map indicated that approximately 60 of the events were of sufficient magnitude and proximity to populated areas to be reported as "felt" while five of the events were of magnitude five or greater, including the February 2001 M6.8 Nisqually earthquake near Olympia, Washington. Interpreting these data is complex and fraught with uncertainty. While scientists have not identified a cause and effect relationship between small earthquakes and big earthquakes, they are confident in a probabilistic relation between the two. UC Davis Professor Donald Turcotte, in a National Public Radio interview noted that a first approximation of earthquake prediction is that "Big earthquakes occur where small earthquakes occur.[164] The two leading scientific bodies researching the seismic threat in Southwestern British Columbia, the United States Geological Survey and the Geological Survey of Canada, produced two very different risk assessments due to variances in the

[163] Clague, John
[164] "Scientists Work to Predict Earthquakes" [Donald Turcotte and William Baulkin] Talk to the Nation (Ira Flatow, Interviewer) Broadcast October 14, 2005, Story # 4958959 Available online at: www.npr.org

assumptions used in producing hazard assessments for the region.[165] Resolving these differences and refining the hazard assessment remains the domain of scientist, but responding to this uncertainty with prudence is the task of those responsible for emergency planning.

Figure Ten: Earthquakes in Southwestern British Columbia over the past 5 years. (2000 10 29 – 2005 10 27)



Source: Natural Resources Canada, http://www.pgc.nrcan.gc.ca/seismo/recent/bc.5yr.html

Figure Ten clearly demonstrates the regional characteristic of the seismic hazard. However, mapping out the decision-making jurisdiction against the geographic scale of this hazard illustrates some of the fundamental challenges to sustainable hazard mitigation for hospitals in the Lower Mainland. Hospital emergency preparedness must take place with a view of the hospital's function in serving its immediate community and the surrounding regions. As indicated in the literature review, the decision-making context begins with federal and provincial governments who act as financiers and regulators. Compliance with these regulations and development of standards necessary for the safe operation of hospitals in Canada are monitored and enforced through the accreditation process led by the Canadian Council on Health Services Accreditation (CCHSA).

[165] Adams, John and Stephen Halchuk, "Knowledge of in-slab earthquakes needed to improve seismic hazard estimates for southwestern British Columbia" Geological Survey of Canada, 2001 Available online at: http://www.seismo.nrcan.gc.ca/hazards/inslab2000/index.php

At the site level, funding decisions about emergency preparedness are made at various levels of the organization. First, individual department managers make decisions and recommendations for risk mitigation measures to individuals responsible for emergency management at the facility. The emergency planner then take all of these recommendations from various departments, organizes the information, and attempts to set priorities. These priorities are in turn reviewed by senior hospital management, who then submit the recommendations to management at VCHA. VCHA managers review this information and subsequently make decisions about which options to pursue and then seek funding for these options from provincial and federal funding sources.

Organizational complexity is not the only challenge in decision-making to reduce vulnerability at St. Paul's Hospital (SPH). Vulnerability, defined as a "measure of the capacity to weather, resist, or recover from the impacts of a hazard in the long term as well as the short term,"[166] is largely determined by previous decisions about risk mitigation, consequently emphasizing Keeney's notion of the "sequential nature of decisions."[167] Risk mitigation choices made, and not made, in the past now define SPH's current vulnerability, and limit the range of mitigation strategies it may now pursue.

Vulnerability and Planning at St. Paul's Hospital

Characterizing the overall vulnerability of the facility to power and water outages depends on such a large number of factors that it becomes nearly impossible. The source of the outage is illustrative of the variation one can expect in terms of the facility's ability to respond to the outage. Let us consider the simplest example of a power outage in order to illustrate the complexity facing decision makers.

Consider a power outage caused by a technical failure in BC Hydro's grid. These outages have impacted Providence healthcare before, and will likely do so

[166] Mileti, Dennis *Disasters by Design* Joseph Henry Press, 1999 p. 106
[167] Keeney, Ralph "Decision Analysis: An Overview" in Operations Research, Vol. 30, No. 5, September-October 1982

again. In March of 2005, Providence's other Vancouver area hospital, St. Joseph's power failed and the entire facility was forced to rely on EPSS.[168] The impact of this outage would depend greatly on the time of day it occurred, and the length of the outage. Hospital operations typically peak during regular business hour, with operating rooms (Ors), outpatient treatment, diagnostics and laboratories all operating at or near their peak capacities. During the night, demand for services will likely be highest in the Emergency Department, but much lower in other parts of the hospital. Thus, if a power outage were to occur at 2am, the impact would like be low. St. Paul's hospital EPSS consists of 5 generators, only 2 of which are required to operate in order to meet essential power demand. The hospital has invested heavily in upgrading the generators and switches, enabling it to re-route power should one generator fail to operate.[169] The generators are designed to operate within 10 seconds of an outage and are tested weekly under load to ensure compliance with this standard. In all likelihood, if an outage of a few hours were to occur at 2am, the impact on the hospital and patient care would be negligible. However, it is easy to imagine only slightly more complicated scenarios that would substantially increase uncertainty about the outcome.

If the same outage were to occur at 10 am on a weekday morning, the consequences could be substantially greater. First, at that time of day, all 12 of St. Paul's operating rooms are normally in use. Essential equipment in the OR and ICU are supported by Uninterrupted Power Supply (UPS), but the welfare of patients undergoing surgery at the precise moment of the outage would be dependent on the reliable operation of the EPSS. For example, a former nurse at Vancouver General Hospital related his direct experience with complete power failure in the ICU that occurred in 1983 or 1984. In his words, it was "complete panic while everyone scrambled for flashlights in pitch darkness and manually ventilated patients." The outage lasted for only one hour, and fortunately there

[168] Denys Carrier, St. Paul's Hospital, Emergency Planning Team Leader, Interview by Darren Cole, 23, March 2005
[169] Denys Carrier, Ibid.

were no casualties or deaths.[170] While testing protocols of EPSS have been increased since then, it is not inconceivable that EPSS will fail to operate when it is most needed, as demonstrated by the 1.5% failure rate during the 2003 Northeast blackout. Moreover, while technology and procedures have likely increased EPSS reliability since 1983, technology has intensified reliance on electrical power to provide medical care since then too.

This illustrates how similar outages can lead to different outcomes. Ex-post adaptation also plays a role in determining the outcome of these outages. For example, contingency plans that call for training non-medical staff to assist medical staff in the event of a power failure could greatly increase the ability of the unit to function under emergency conditions. Consider a power failure in the ICU. When this occurs, patients require immediate, and ongoing, manual ventilation in order to survive. This means that key medical staff are now dedicated to performing this function, unable to coordinate a strategic response to the emergency. If on-site, non-medical personnel were trained how to assist in this effort, it would free medically competent staff to engage in prioritizing the response of the ICU to the power emergency. While implementing this type of ex-post adaptation seems straight-forward, it represents a complex training task that involves questions of medical risk and liability, substantial changes to job descriptions that may impact union rules and salary requirements and ongoing training and practice of these types of emergency procedures.

The impacts to the hospital under this type of outage scenario would be contingent on the duration of the outage. Almost immediately, non-emergency surgeries would be cancelled until reliable power has been ensured. This means a substantial loss of income for the hospital and creates complex logistical challenges to re-schedule the affected surgeries. Furthermore, consequences can propagate to include larger political impacts such as concerns of delays in patient care and exacerbating wait-times. In spite of these obvious financial and social impacts, the question for emergency planners is "Can further investment in EPSS mitigate these costs?" What this really asks is should EPSS power, under

[170] Anonymous Interviewee, Interview by Darren Cole

a normal outage scenario, be considered reliable enough to continue non-emergency and emergency surgery in the hospital?

This is a complex question relating to the technology employed by the EPSS system. For example, some EPSS systems are actually small-scale independent power generation systems wherein the 'normal' power for the hospital is provided by the onsite generator, with EPSS supplied by a connection to the local power grid, and further EPSS back-up should both the generator and local power grid fail. Montefiore Medical Center.[171] Thus, decision-makers need to weigh the costs of installing this type of system with the benefits it will provide. However, based on discussions with emergency planners, it appears that decision-makers consider EPSS systems only in terms of back-up for infrastructure failure, not as an alternative to it.

The impacts of the power outages on SPH discussed this far have focused on short-term durations. If the outage is short-term, and site-specific only, the broader impacts of the outage are likely to be minimal. Under a power outage scenario, on-site representatives of hospital departments (ED, ICU, nursing, administration, respiratory therapy etc.) would meet to discuss and determine the operational capacity of the facility in terms of the number of patients it can handle, what types of treatments it can support, and diagnostic services that are available. Here, the nature of the outage will have important impacts on the outcomes. For example, if the EPSS has failed, and essential diagnostic equipment such as MRI scanners are not available, under normal circumstances the hospital must close its emergency department. This would create an ED diversion where ambulances would be redirected to other emergency departments within the region. These types of events occur for a number of reasons throughout the year, and the healthcare system and personnel are adept at dealing with the challenges ED diversion creates.

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[171] Haefke, Clifford "Combined Heat & Power (CHP) for Minnesota Healthcare Facilities" Presentation to Healthcare Environmental Awareness & Resource Recovery Teamn (HEARRT) Thursday, January 8th, 2004 Available online at: http://www.chpcentermw.org/pdfs/040108_chp_hearrt_haefke_StPaul_MN.pdf

Beyond mandatory diversions, hospital officials need to assess their ability to offer care, and manage patient numbers accordingly.

The demand for hospital beds, and ICU beds in particular, is high. To manage access to hospital beds, most hospitals, including SPH, hold meetings daily, and frequently more than once per day, to determine bed occupancy and vacancy rates. ICU beds are critical and impact the availability of all other beds and services. For example, without sufficient ICU beds available, the ED may be forced to temporarily close. Thus, ICU department managers and healthcare professionals attempt to transfer ICU patients to other in-patient care areas of the hospital as soon as medically acceptable. In turn, in-patient care managers need to balance the influx of ICU and other patients into their wards with patients being released to home care. In a power outage scenario, hospital officials would first free up hospital bed resources by releasing as many patients as possible to home care or alternative care facilities such as Senior's Care homes. This adaptation will enable the facility to continue to offer quality emergency care, but at the expense of impaired chronic care. Moreover, the decision to release patients to alternative care facilities is at the medical discretion of their doctors. This presents a tough dilemma for the hospital and doctor alike. On the one hand, the hospitals core mission is supported by the early release of patients who would normally stay in the hospital. However, physicians, who may not be employees of the hospital, face the difficult decision, and potential ethical and legal liability, of which patients to release based on their medical conditions. It is important to remember here that in today's healthcare context, the pressure to release patients soon after treatment is already great, in order to minimize costs to the healthcare system and free-up resources for other patients.

The magnitude of the impacts of a power outage will quickly escalate as the duration increases. The EPSS system is never tested under conditions that reflect the rigors of extended operation under load. This increases the likelihood of a technical failure in the system. While SPH has contracts in place for priority fuel replenishment, it maintains only a 72-hour supply of diesel fuel on site. Given the aforementioned potential disruption to critical transportation routes, it is possible that fuel replenishment may not be possible in time to avoid total power loss. Second, if a large earthquake is the originating event of the outage, it may be difficult to obtain service for the EPSS should any failures occur. Thus, the vulnerability of EPSS is highly contingent on both the length of the outage, and the originating event of the outage.

Assuming the EPSS continues to function throughout the emergency, the impacts on the hospital are difficult to predict. First, only areas of the hospital that are critical to the function of the hospital have emergency power. Many administrative buildings, including the building where the emergency planning office is located, do not have emergency power. In an extended outage, it is foreseeable that the loss of key administrative services will begin to take a toll on the ability of the hospital to continue to offer emergency services. Second, non-emergency surgery will be cancelled, creating a substantial financial loss to the hospital. Third, ancillary services such as food services, laundry and housekeeping will be severely impaired by the power outage. This will make evacuation of the hospital for all but critical care patients probable. The consequences of mass evacuation of the hospital will have ripple effects throughout the regional healthcare system.

The physical resources required to move infirm and ill patients will not be small. At SPH, the narrow staircases that prohibit evacuation of patients on medical gurneys amplify this difficulty.[172] The prospect of evacuating patients down several flights of stairs through narrow, dark staircases is one that sends shivers down the spines of anyone concerned about emergency preparedness. The second impact of an evacuation at SPH would be that Emergency Medical Services (EMS) personnel and equipment would be called in to move the patients to the alternate location, rather than supporting ongoing search and rescue operations. Third, the capacity of the alternate facility to absorb the influx of patients is likely to be limited, given that it to may be operating on EPSS power. Staff from SPH would likely accompany SPH patients and take primary responsibility for their care. While this would reduce the demand on the alternate

[172] Denys Carrier, Ibid.

facility somewhat, issues such as equipment shortages that occurred during the Mount Herman Hospital evacuation in Houston, Texas would become problematic. While this is a simplified sketch of potential impacts of an evacuation scenario due to power outages, it clearly demonstrates how evacuation of a hospital due to power outage would reduce the capacity of the hospital system due to the loss of the facility itself, but perhaps of even greater importance, the system's capacity would be severely reduced due to the inefficiency and overcrowding in alternate facilities that receives the evacuated patients.

Other impacts that must be planned for go beyond the loss of power, and include such concerns as the availability of critical medical supplies onsite. Hospitals have increased their operational efficiency during normal operations by adopting just in time delivery practices for many critical supplies. In general, SPH maintains a 72-hour supply of medical supplies, key medicines, housekeeping linens, and sanitary supplies. However, demand for various supplies will vary greatly depending on the emergency, and other changes to the medical infrastructure of the region under an outage scenario. Even without widespread trauma caused by seismic disaster, demand on hospitals for emergency care will increase significantly under any power outage scenario. Electrical power dependent patient such as those on oxygen, renal care and other home medical treatment equipment will require hospitalization if no other powered facilities are opened to meet this demand. Second, even minor medical conditions will now require the service of hospitals with EPSS because most outpatient facilities such as physicians and out-patient diagnostic services (managed under contract by MDS Laboratories in the Lower Mainland) will not have power to offer service. Thus, routine medical needs will no longer be served by these facilities, shifting the demand to hospitals where there is functional EPSS. In the aftermath of Hurricane Wilma in Southern Florida, hospitals were forced to deal with a significant increase in routine medical problems such as minor injuries, treatment of chronic conditions, and even pharmacy services because the widespread power outage in the aftermath of Hurricane Wilma decimated the region's healthcare infrastructure.[173]

Improved emergency planning offers significant opportunities to reduce the impacts of this induced demand on hospitals. The most obvious solution is to use disaster medical assistance teams to provide basic medical care and assist in triaging patients for more specialized care in hospitals. Another possibility in Vancouver is to use the provinces 200-bed emergency hospitals. These are facilities that can be set-up in public buildings such as recreation centres or school gyms. The hospitals provide the basic infrastructure to offer medical care, but are not staffed. Moreover, the use of these hospitals requires that they be transported into a suitable site, with sufficient volunteers to set-up the facility, and the ability to locate medical staff competent to offer medical services.[174] Moreover, in such basic and unfamiliar conditions, efficient care will be a severe challenge. Clearly, in a catastrophic disaster, the usage of these temporary hospitals may well be required. But given the delay in setting them up, the costs, and problems staffing them, it may be better to consider how to integrate disaster planning into the community's existing healthcare infrastructure.

To do this a combination of investment, education coordination is needed. First, community's need to identify which healthcare resources beyond hospitals are critical during an emergency. Facilities such as Seniors Care Homes, medical buildings housing family doctors and the like, and medical diagnostic laboratories are examples of these types of facilities. Once identified, investment in seismic upgrades and EPSS may be required to increase their abilities to function without electrical power. The second step is to work with the community beforehand to increase awareness about the care options available in an emergency, so that the public can participate in making better decisions about where and when to obtain medical care in an emergency. This can be done

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[173] Trujillo, Melissa "Florida ER's Swamped in Wilma's Aftermath" Associated Press, October 30, 2005 Available online at: http://sfgate.com/cgi-bin/article.cgi?f=/n/a/2005/10/30/national/a144651S88.DTL&type=health

[174] Smith, Chris "Canada's National Emergency Stockpile System (NESS): "A Health & ESS Resource" presented at 18th Annual Emergency Preparedness Conference, Vancouver, Canada. October 4, 5, 6 2005

effectively through posting information in Physician's clinics and with emergency numbers listed in telephone directories. Moreover, this emergency preparedness program dovetails nicely with the ongoing need to educate the pubic about the function of hospital ED departments to reduce costly unnecessary visits. The Canadian Institute for Health Information found that over 50% of visits to hospital emergency rooms are for less-than-urgent conditions.[175]

Impact of Water Outages

To date, SPH has not experienced a water outage. Thus, planning and decision-making about mitigating the impacts of a water outage are based on assumptions about the probabilities of such an outage occurring. While the probability of such an event occurring is low, the consequences are catastrophic in terms of the hospitals ability to perform its mission: "I don't know how long we could go without water. Period."[176]

Contingency planning for water outages was prompted by concerns of widespread infrastructure failures that may have arisen due to the so-called "Y2K" computer glitch on January 1, 2000. SPH had three tanker trucks of water on-site in case the worst fears of failure were realized. However, hospital officials doubt the efficacy of water tanker trucks of meeting the water needs of the hospital. They estimate that one tanker truck could only supply water for 1 hour's worth of demand from kidney dialysis machines. For example, a typical single-axel water truck holds a 2000-gallon water tank. A typical water flow rate for a kidney dialysis machine ranges from a low of 6 gallons per minute to a high of 10 gallons per minute.[177] A typical kidney dialysis treatment lasts 3-5 hours, and needs to be performed three times per week. At minimum, a single treatment requires 1080 gallons, and at most, requires 3000 gallons.

Water is also critical for a number of other functions. For one, it is used in the chillers that provide cool air to the hospital. Depending on the time of year of

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[175] Globe and Mail "Most Canadian ER visits not emergencies" in *The Globe and Mail* September 14, 2005 Available online (archived) at: http://www.theglobeandmail.com
[176] Denys Carrier, ibid.
[177] Northwest Renal Network, "Monitoring Your Dialysis Water Treatment System" June, 2005. p. 16 Available online at: http://www.nwrenalnetwork.org/watermanual.pdf

the water outage, this failure could prove critical to patient care. Clean water also plays an important role in infection control and sanitation in the hospital. In the absence of water, the hospital could continue its infection control regime through the use of germicidal products that do not require water, but over time maintaining sanitation in the facility would prove exceptionally difficult without water for toilets and cleaning. Third, a lack of water would mean the hospital could no longer produce food for its in-patient population. Last, the loss of water would mean that the facility's fire-suppression systems are severely impaired. Under normal operations, it is illegal for the hospital to operate without a code-certified fire suppression system. While it would likely be given permission to continue operations under these extraordinary circumstances, the risk to the well-being of staff and patients alike is increased.

In an extended water outage scenario, SPH has one adaptation measure that it could take to mitigate the outage's effects on sanitation at the hospital. It is technically possible for SPH to connect to Vancouver's emergency firefighting water network. This system is designed to provide the city with emergency firefighting capacity by pumping saltwater through a separate pipe network. The advantages of doing so would be to supply water to equipment such as toilets and fire-suppression. However, the long-term impact of this temporary solution would likely offset any short-term benefits, as the salt water would likely cause damage to the piping water piping systems.

A different, and perhaps more likely, scenario would be not a complete water failure, but a scenario where water is no-longer potable due to damage to water treatment systems. The impact of this type of failure will be discussed in the Los Angeles Case study section as this failure occurred in the 1994 Northridge Earthquake.

At the site level, the alternatives to mitigate the impact of water outage are few. Given the apparent limitations of water tanker trucks to meet the emergency needs of the hospital, other solutions have been considered. One solution would be to install a seismically reinforced water storage tank. Assuming the systems survives the seismic event, which it is likely to do,[178] a water take(s) of sufficient storage capacity would provide adequate emergency water. Another potential solution is to access groundwater on the site, as the Chang-Gung Memorial Hospital in Linkou has done. Of note, Denys Carrier has indicated access to groundwater is a priority that he is working to ensure is incorporated in the site plan for the new facility should it be constructed. In the meantime, SPH has developed water conservation plans on a departmental basis which calls for water saving actions such as not flushing toilets and storing water in bathtubs. However, Mr. Carrier is not optimistic about how much these actions will help.[179]

According to Mr. Carrier, the issue of vulnerability to water outages is a much larger issue that needs to be tackled at the provincial level. He notes that decision-makers have been aware of this issue "for years," but that no action has been taken by those capable to do so. Moreover, given the potential of water storage tanks to significantly mitigate the impacts of a water outage and the success other facilities have had with water tanker trucks (see the Los Angeles case study) it seems that further consideration of the ability to mitigate water outages on the current site in a financially viable way is merited.

Learning from Past Outages

In terms of mitigating future disasters, it is important for disaster planners to understand the ways in which systems fail (mainly an engineering and technical responsibility) and to incorporate sound organizational learning strategies to capitalize on past experiences and reduce uncertainty. One way that SPH attempts to incorporate learning in its disaster preparedness work is to maintain a database that tracks incidents, reviews procedures with staff involved in the incident, and then revise procedures based on the new information. The database is maintained by the emergency operations centre, and includes information on events that effect patients, staff and visitors to the facility. On average, 100-110 such codes are entered on a monthly basis (not all of which

[178] Jay Lewis, Ibid.
[179] Denys Carrier, Ibid.

pertain to electrical or water issues), and 99% of the time, these incidents result in changes to existing procedure to reduce the likelihood of recurrence.[180]

One of the incidents contained in the database relates to unexpected failures may result from extended EPSS operation. One example of this type of failure occurred during routine maintenance to the hospital's Private Branch Exchange (PBX) equipment. PBX is critical to the operation of the hospital's telecommunication systems. As such, it is supported by EPSS back-up and battery-power backup that is designed to support operation of the PBX for six hours. However, when disconnected from the power supply due to routine maintenance, the PBX batteries were depleted after only 30-minutes of use, and regular power was rapidly restored to avoid communication systems failure. Given the complexity of electrical power dependent systems, these types of unexpected failures are difficult to avoid. "One assume things are fine because there was never a problem before, because never needed them before [PBX back-up battery power] but when needed, we discovered problems with the contract service. How can we really check to ensure compliance?"[181]

The failure of the PBX system touches on a related vulnerability facing hospitals, the need to contract critical emergency preparedness capabilities to third parties. Hospitals in the lower mainland have faced rising demand for care; increasing efficiency is an effective means of meeting rising demand while funding remains stagnant or even declining. By contracting out maintenance services, hospitals gain cost certainty over some operational costs such as generator maintenance and communication systems while maintaining compliance with regulations about maintenance and testing. The downside is of course a partial loss of control over the day-to-day inspection and repair of these critical infrastructures, and reliance on the ability of the contractor to fulfill the contract. SPH's experience with their PBX system indicates that there is uncertainty in the ability of contractors to meet the terms of the contract. Beyond this, by their nature, third party contractors are not located on site, thus in the

[180] Densy Carrier, Ibid.
[181] Denys Carrier, Ibid

event of a failure during an emergency, the ability to repair critical back-up infrastructure is contingent on the ability of the contractor to reach the hospital site and effect a timely repair.

In spite of significant progress, SPH remains vulnerable to prolonged electrical outages, seismic events, and water supply interruptions of any length. The hospital has invested in structural retrofitting that ought to ensure the survival of the structure, but given the age and construction materials of the building, there is greater uncertainty of this outcome. Additionally, the hospital has not completed efforts to restrain equipment, piping, and drop ceilings to prevent serious injuries or death in a major earthquake.

In an electrical power outage scenario that does not involve a concurrent disaster, the facility's EPSS ought to perform well. The hospital has an extensive testing regime, and has invested heavily in ensuring that the switching equipment that provides the vital link between the generators and the hospital are capable. The facility also stores three days of diesel fuel on site to power the generators, and has contracts with fuel supply companies to ensure priority supply during a power outage. Beyond its technical resilience, SPH has worked to develop emergency power protocols and back-up procedures to ensure an orderly, functional hospital. Staff call-up plans are in place, back up patient documentation systems are in place should computer systems fail(which are connected to EPSS) and communications technology has been improved so that SPH can communicate effectively with Vancouver Coastal Health Authority and Vancouver's Emergency Operations Centre. Thus, in a simple power outage scenario should not seriously impair the operation of the facility. However, if the same outage were extended, the ability of the hospital to maintain emergency operations would decline, as generators and other emergency equipment have not been tested under load for extended periods of time.

In a water outage, the impact on the hospital would be almost immediate. Quite simply, SPH does not have water back up capacity. If sufficient alternative water supplies could not be established, the hospital would be forced to evacuate within hours of the onset of the outage. Moreover, as alternatives have not been explored nor developed in the current plan, the likelihood of a timely resolution to this problem in an emergency is even less likely. This is a critical vulnerability that remains to be addressed.

In an outage scenario caused by a seismic event, it is highly unlikely that SPH will be able to offer even emergency care. First, the water infrastructure of Vancouver is highly vulnerable to seismic shaking. SPH's critical dependence on functioning water infrastructure means that in a large earthquake it will likely require evacuation until water is restored, even if other systems in the facility remain operational. Beyond the immediate aftermath, the age and lack of non-structural mitigation at the facility could mean an extended closure. One can expect substantial water damage to the facility and key medical equipment caused by failed pipes. The ability of the hospital to recover and offer medical care at an alternative site is limited by the lack of detailed planning about the location and staffing of such a facility. While bleak, this assessment is likely to change for the better as hospital planners and administrators continue to work to reduce the vulnerability of SPH to this type of scenario.

4.5 Los Angeles Case Study: Northridge Hospital Medical Center

The urban landscape of Los Angeles has been subject to much critical analysis by urban planners and seismic experts alike. A global city situated at the edge of the Pacific Ocean, the richness and diversity of Los Angeles' urban landscape defies those who wish to define it. It is a city that "appears as an intensely privatized, anarchic version of urban growth . . .Urban outcomes have consequently been the product of a *public/private dialectic* in which the hegemony of either sector has periodically shifted . . ."[182] The complex urban and political fabric of Los Angeles is reflected in emergency preparedness planning for hospitals in the area as planners grapple with strong legislative

[182] Dear, Michael "In the City, Time Becomes Visible: Internationality and Urbanism in Los Angeles, 1781-1991" in The City: Los Angeles and Urban Theory at the End of the Twentieth Century Allen J. Scott and Edward W. Soja (eds.) University of California Press, 1998

regulations for disaster mitigation on the one hand, and with complex, diffuse decision-making structures on the other.

California planners and legislators in California have long recognized the region's seismic vulnerability and have put in place increasingly stringent building codes to reduce vulnerability. Current building codes in California, especially those that pertain to hospitals, are among the most advanced and stringent in the world. Yet the seismic vulnerability of hospitals is more profound than simply the integrity of the building code. The simple fact remains that more than 30 years after the passage of the Alfred E. Alquist Facility Seismic Safety Act of 1973 facility compliance has not kept pace with increasing knowledge and stringent standards emerging from new understandings of seismic risk. For example, only 323 of 2507 hospitals meet current standards.[183] Of the facilities that do not meet current standards, 1807 of them fail to comply because of non-structural vulnerabilities.[184] Most alarmingly, as of 2001 (the most recent information available) only 14 hospitals in California meet current guidelines in their entirety and can be expected to function for 72 hours independent of utility-based water and electrical power sources, assuming structural and non-structural mitigation measures function as designed.[185] The impact of legislation in reducing vulnerability to the seismic threat in California and thereby providing better healthcare to Californians during emergencies is uncertain.

Senate Bill 1953: Policymaking and Decision Analysis

The 1971 San Fernando Earthquake increased politicians' and decision-makers' awareness of the seismic risk facing hospitals in the greater Los Angeles area. The next year, the California State Legislature passed the Hospital Safety Act 1972 with the stated aim of ensuring hospitals are "reasonably capable of

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[183] Seligson, Hope, Shoaf, Kimberley, and Shinozuka, Masanobu "Multi-Hazard Modeling of Medical System Performance" p. 4 \

[184] Seligson, Hope and Shinozuka, p. 4

[185] Office of Statewide Health Planning and Development "Summary of Hospital Seismic Performance Ratings April 2001" 2001 Available online at: http://www.oshpd.ca.gov/SB1953/sb1953rating.pdf

providing services to the public after a disaster . . ."[186] This legislation was further strengthened in 1986 by the California Hazards Reduction Act of 1986. This piece of legislation foresaw a thirty-year implementation phase to vacate, replace or upgrade hospital facilities to comply with 1986-era building codes. These proposals were packaged in a report titled "Milestone Four" which were not acted upon until the 1994 Northridge earthquake which prodded lawmakers to embrace these recommendations, passing them into law as Senate Bill 1953. (SB 1953)

The introduction of SB 1953 provides some unique insights into how even the best intentions can go awry in decision-making. While not examining the history of this legislation in detail, it is sufficient to say that the intention behind the bill was to improve healthcare in California by making hospitals less vulnerable to seismic hazards. Sponsors of the legislation sought to do so by creating rules that acute healthcare facilities were required to improve the building and content performance to a level designed to ensure safety and operational capacity. This was an attempt to improve the efficiency and access to healthcare in the crucial first 72 hours following a major seismic disaster. From a technical view, this legislation does call for significant improvements that ought to make hospitals that comply with the rules less vulnerable to seismic risk. SB 1953 represents one logical approach to solving this problem: tougher building codes. However, that is just one alternative. Moreover, as California has long pursued seismic risk mitigation through increasingly stringent building codes, one wonders if the law of diminishing returns has set in and policy makers must seek new alternatives for sustainable disaster mitigation strategies. Dennis Mileti cautions us that "many of the mitigation activities...are not preventing damage but merely postponing it...it is worth emphasizing that eventually nature will provide an event more extreme than that anticipated in plans and designs."[187] Consequently, decision-makers must look beyond technical solutions to reducing

[186] Holmes, William "Program for Seismic Rehabilitation of Existing Hospitals in California" presented at Pan Pacific Hazards 96, Vancouver, 1996. Available online at: http://www.ruthchek.com/flash/ frame2/who/resume/WTHSB1953link.pdf
[187] Mileti, Dennis 1999 p. 25

risk from disasters to incorporate complementary mitigation strategies, such as stringent land use regulations in hazardous areas. These strategies will likely require painful short-term adjustments in some areas, but potentially greater, more sustainable, risk reduction. By reducing the number of people vulnerable to seismic disasters, planners would also alleviate the demand for emergency healthcare following a disaster.

From a broader perspective it is possible to argue that the bill has failed in its goal to improve California's healthcare system. Petak and Alesch, two experts in disaster mitigation policy who have studied the impact of SB 1953 in depth, have noted that the effort to improve safety in healthcare institutions and rapid changes in the financial environment for healthcare institutions such as managed care have resulted in unanticipated outcomes, such as hospitals closing acute care facilities rather than comply with stringent regulations.[188] . Furthermore, the retrofit strategy implicit in the legislation combined with other changes in building codes such as asbestos control standards that would have further raised costs of compliance with SB 1953 and other legislation.

According to Petak and Alesch, SB 1953 was framed as retrofit problem by those who drafted the legislation, but healthcare decisions makers, charged with responding to the legislation, viewed it in the strategic context of their organizational objectives and longer-term development. The key objectives for them were immediate affordability, long-term financial viability, serving their organizational mission, and regulatory compliance.[189] These objectives appear to differ significantly with the objectives of SB 1953 which was framed in a context where "hospital regulators and structural engineers were genuinely concerned about the potential effects of seismic events on hospital patients, staff, and capacity."[190] In many cases, the only aspect of convergence of objectives between healthcare administrators and legislation resulted in closure of older facilities. If healthcare administrators operated other, more modern facilities,

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[188] Petak, William J. and Daniel J. Alesch "Organization Decision-making with Respect to Extreme Events: Healthcare Organizations Respond to California's SB 1953" http://www.mceer.buffalo.edu/publications/ resaccom/0304/09_alesch.pdf
[189] Petak and Alesch, p. 139
[190] Petak and Alesch p. 131

they could close the non-compliant facility while preserving their long-term organizational and financial goals, and ensure regulatory compliance. As noted, 2 500 hospital beds were closed in the immediate aftermath of the Northridge earthquake. Perversely, after SB 1953, thousands more hospital beds have been eliminated, mostly due to the costs of treating uninsured patients, but inevitably the higher costs of seismic compliance contribute to this disturbing trend and decline is system capacity.[191]

The result is a healthcare system under extreme pressure even without an earthquake. Trauma beds have been sharply reduced, and hospital bed occupancies in California run almost at capacity on a daily basis. If an earthquake were to occur, it is foreseeable that the healthcare system may be less-equipped to respond than it was prior to SB 1953, even if healthcare structures perform better during the quake simply because the system is already operating at near capacity and it will take time to ramp up capacity and triage patients even with an operational facility and full power and water.

While further research is required to determine the ultimate outcomes of SB 1953, the short-term upheavals that have been created by the legislation demonstrate the need for an inclusive, multi-stakeholder approach to decision-making about risk mitigation in healthcare facilities. With more complete participation from all stakeholders including government, seismic safety experts and engineers, hospital administrators and staff, medical insurance companies, and the community representatives, it might have been possible to develop a more holistic alternative that met the safety goals of SB 1953 while preserving access to healthcare services. Undoubtedly, this approach may have led to trade-offs, some that may have even reduced the level of safety during an earthquake, or others that would have raised the cost of healthcare, or still others that lowered the profitability of offering healthcare services.

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[191] Madigan, Nick "Los Angeles Emergency Care Crisis Deepens" *New York Times,* August 21, 2004 http://www.cepr.net/Economic_Reporting_Review/nytimesarticles/la_emergency_care.htm

Northridge Earthquake Summary[192]

The 1994 Northridge earthquake measured M6.7, killed 57 people, injured 1500 and caused moderate to severe damage to 12 500. Despite the strength of the ground motion, the earthquake caused relatively few injuries and deaths because it occurred early in the morning on a holiday. Three days after the earthquake 9 000 homes were without electricity and 48 500 had little or no water. Major damage to freeway structures as far as 32km from the epicenter plunged Los Angeles into traffic chaos. The earthquake also triggered several fires.

The earthquake caused some of the strongest ground motions ever recorded and occurred directly beneath the densely populated San Fernando Valley, with most of the damage located within 16 km of the epicentral area. The Northridge Hospital Medical Center (NHMC) is located within this epicentral area and offers an informative case study of the impacts of a moderate earthquake in a densely populated urban area.

Northridge Hospital Medical Center

The Northridge Hospital Medical Center (NHMC) has served the 1.9 million residents of the San Fernando Valley for over fifty years. NHMC, shown in Figure Eleven, is part of Catholic Healthcare West(CHW), California's largest not-for-profit hospital provider with over 40 hospitals, 40 000 staff, and 6 782 acute care beds.[193]

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[192] Adapted from: EQE International "The January 17' 1994, Northridge, CA Earthquake. An EQE Summary Report, March 1994. Available online at: www.eqe.com
[193] Catholic Healthcare West, "About Us" Available online at: http://www.chwhealth.org/stellent/websites/get_page_cache.asp?nodeId=5005410

Figure Eleven: Northridge Hospital Medical Center

Photo by Author

Given the expense of emergency preparedness and SB 1953 compliance, it is worth considering an overview of CHW's financial position in terms of how its funding mechanism, and therefore decision-making context differs from other hospitals in the study. CHW funds its operations through revenue generated by offering healthcare services. It also actively borrows money through bond markets and as such, the financial risk of these bonds is reported by investment rating firms. According to Moody's Investor Services in 2005, CHW's ". . .greatest challenge is to fund its very large and growing capital program and, as in the past, to apply appropriate spending constraints if necessary."[194] Financial constraints on capital programs are common among all hospitals studied in this thesis. However, in the case of NHMC, the financial options available for risk mitigation are directed toward CHW, which in turn, borrows funds through the California Health Facilities' Financing Authority, the California Statewide Development Authority.

Instead of seeking financing through government programs, CHW seeks investment funds through the public bond market, and thus, is subject to market

[194] Moody's Investor Services, "Rating Update: Catholic Healthcare West" August 12, 2005 Available online at: http://www.chwhealth.org/stellent/groups/public/@xinternet_con_sys/documents/webcontent/096895.pdf

forces to offer a competitive return for the perceived risk inherent in its debt. It is for public health experts and economists to argue the relative merits of these different funding methods; for the purpose here, the funding mechanisms for capital projects (which include seismic retrofit programs and EPSS) demonstrates the structured relationship between the state as a regulator, and the healthcare organization as a separate entity. This form of regulation also benefits from the information provided to the public and others interested in risk mitigation for hospitals in California.

In both Taiwan and Canada, it is far more difficult for the public and researchers to gain a practical understanding of a facility's emergency preparation level, and the challenges it faces in reducing vulnerability. Moreover, according to one source intimately familiar with hospital decision-making about nonstructural mitigation, in Canada, decisions to take mitigation action are not made at the facility level. The hospital will only act if it has a budget for mitigation.[195] In NHMC, the decision-making protocol is different. NHMC has one full-time staff member that works on financial analysis of the benefit/cost of SB 1953 compliance. This individual works with the hospital's engineering staff on a daily basis to develop cost-effective solutions and alternatives to achieve compliance with the regulations. After all, if the hospital fails to comply, it may be forced to suspend its operations, at significant loss of revenue and damage to its reputation. Clearly, the decision-making process that emerges from accreditation standards and SB 1953 create a decision-context quite different from that of the other case studies: mitigation is viewed as a necessary cost of continuing hospital operations, not an ancillary budget item to be invested in when funds are made available by the regulating body.

Consequently, it is possible to view the decision-making context of emergency preparedness in Californian hospitals squarely in terms of the 'rule-following' paradigm discussed by March and Kahneman. Thus, one would expect satisficing decision-making whereby mitigation decisions are taken based on the need to reach compliance with the regulations. By separating the

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[195] Jay Lewis, Ibid.

legislation that creates minimum emergency preparedness standards from financing that compliance, regulators can demand compliance. The upside of this relationship is that regulators have punitive power to ensure compliance; vulnerable facilities can simply be closed. However, as Petak and Alesch demonstrate, rational decision-makers, in compliance with the rules, can simply elect to close the facility, thereby ensuring compliance with the regulations, but failing to make hospitals less vulnerable to disasters as the legislation envisioned. The rate of hospital closures, especially emergency rooms, has increased substantially in recent years.[196] Closing emergency rooms appears to be mostly related to the fact that such closures reduce hospitals' financial liability to treat uninsured patients, but many administrators have indicated disaster preparedness is also a substantial factor in these decisions. Beyond compliance through investment or closure, a third alternative has emerged: delay.

One outcome of the legislative context of hospital disaster preparedness in California is the amount of public data available about compliance with the legislation. This increases transparency in decision-making, reflects the improvements hospitals are making, and indicates where further improvement is required. In order to communicate seismic preparedness, the Office of Statewide Health Planning and Development uses a 5-point rating system for both structural and nonstructural performance. The ratings are explained in Table Four.

Table Four: Structural and Non-Structural Performance Ratings Explanation

Structural Rating	Definition
1	These buildings pose a significant risk of collapse and a danger to the public after a strong earthquake. These buildings must be retrofitted, replaced or removed from acute care service by January 1, 2008.

[196] Felch, Jason "Valley's Oldest Hospital to Close: Shuttering of Van Nuys facility will add to the sharply rising toll of ER shutdowns in county." in the Los Angeles Times, August 20, 2004.

2	These buildings are in compliance with pre-1973 California Building Standards Code, but are not in compliance with Alquist Hospital Facilities Seismic Safety Act. These buildings do no seriously jeopardize life, but may not be repairable or functional following strong ground motion. Compliance required by January 1, 2030.
3	These buildings are in compliance with Alquist Hospital Facilities Seismic Safety Act. They may not be repairable or functional following strong ground motion. They can be used to 2030 and beyond.
4	In compliance, but may experience structural damage which could inhibit the building's availability following a strong earthquake.
5	In compliance, reasonable capable of providing services to the public following strong ground motion.
Non-Structural Rating	
1	Basic systems essential to life safety and patient care are inadequately anchored to resist earthquake forces. Hospitals must brace the communications, emergency power, bulk medical gas and fire alarm systems.
2	Essential systems vital to the safe evacuation of the building are adequately braced. Significant nonstructural damage is expected in a strong earthquake.
3	Nonstructural systems are adequately braced in critical areas of the hospital. If the building structure is not badly damaged, the hospital should be able to provide basic emergency medical care following the earthquake.
4	Contents are braced according to the current code. The hospital building should be able to function, although interruption of the municipal water supply or sewer system may impede operations.

5	These buildings meet all the above criteria and have water and wastewater holding tanks—sufficient for 72 hours of emergency operations—integrated into the plumbing systems. They also contain an on-site emergency system and are able to provide radiological service and an onsite fuel supply for 72 hours of acute care operation.

According to the Office of Statewide Health Planning and Development NHMC consists of ten buildings with the following performance ratings:

Table Five: Northridge Hospital Medical Center Seismic Performance Ratings[197]

	Structural Performance Rating					Nonstructural Performance Rating				
	1	2	3	4	5	1	2	3	4	5
Buildings	2	0	7	1	0	0	6	4	0	0

Based on the data in Table Five, NHMC's ability to withstand a major earthquake and continue to offer medical service was questionable as of 2001. The majority of the hospital's buildings (7) has an SPC-3 rating, and thus could be expected to be damaged, but operable in the wake of a strong earthquake. This assessment is reasonable given the facility's experience during the 1994 Northridge Earthquake where three towers joined by short walkways actually separated as designed. This meant that in order to travel from one tower to another, instead of crossing the walkway, patients and staff had to exit that tower, enter the adjacent tower, and return to the floor. Engineers on-site determined that the facility was safe to operate and had not sustained major damage, although it took three months to repair the walkway links between the

[197] Office of Statewide Health Planning and Development "Summary of Hospital Seismic Performance Ratings" April 2001 Available online at: www.oshpd.state.ca.us

towers. While less than ideal, the SPC-3 rating indicates the life-safety of the facility during an earthquake, and suggests that the structure will be functional, though damaged after a strong earthquake.

More troubling are the nonstructural performance ratings. Essentially, as of 2001, none of NHMC's buildings meet current building codes in terms of non-structural performance. Worryingly, six of the ten structures can only be expected to function at a level to permit evacuation of the structure. While these structures are not medically critical facilities within the hospital, the immediate need to facilitate their evacuation could potentially draw on personnel resources that might be required to establish and implement the hospital's HEICS (Hospital Emergency Incident Command System) plan such as setting up exterior triage and treatment stations. Additionally, key support offices such as the emergency preparedness office are located in structures that are not expected to be functional after an earthquake. While not critical to operation of the facility, it is important that plans are in place to support the ongoing operations of the emergency planning staff throughout an emergency.

Impacts of Power Outages

Once again, the key metric of power outages to date is the financial impact of lost revenue. For NHMC, the emergency department is a key revenue driver as most in-patients are admitted through it. In an outage where the EPSS functions, the impact on the hospital is likely to be through lack of capacity in terms of ICU beds, lab diagnostics, and ward beds. Even though all of these areas do have emergency power supply, caution dictates caution in using this capacity which may mean early discharge, Emergency Department (ED) by-pass(if outage is restricted to NMHC) and other similar measures to reduce demand. Hospitals also face increased staff costs due to power outages, both in terms of staff idled by the outage, and extra staff called in to augment critical functions of the hospital made less efficient by the lack of power.

However, if an outage affects critical equipment, statutory requirements may force the closure of the ED. For example, without an operational MRI machine, the facility cannot offer ED service. Another risk is that negative flow air rooms would be inoperable, making the entire facility vulnerable to potential infection. These rooms are not always in use, so the consequence of this failure on the operation of the facility varies over time.

After the loss of the ED, the most serious impact would be on the Operating Room (OR). A sudden, complete loss of power would put several patients at extreme risk. The hospital has attempted to mitigate this risk by placing flashlights in every operating room. NHMC also has several portable electrical power generators that could be physically moved to a site near the OR and connected to the power system to provide enough power to complete surgeries in progress. However, this has not been tested, and remains a worst-case scenario.

The impact on wards would be less immediate, but as the outage grows longer, the need for action would increase. In the wards, much like other hospitals in the study, plans are in place to evacuate as many patients as possible. However, several factors make this more difficult in California. First, as in all cases, patient discharge can only be authorized by a physician: at NMHC, most physicians are not staff of the organization, but have a contractual relationship with the hospital only. Thus, under an emergency, emergency planners at NHMC do not expect many physicians to report to the hospital. Staff physicians are limited to those working in the ED and interns, all of whom would presumably be occupied with responding to emergency care demands. Second, many observers and officials who wished to remain anonymous on this question, point out that in California's litigious healthcare environment, both physicians and hospitals alike would incur a substantial liability and risk by discharging patients. The fear is that if a discharged patient were to succumb to their illness, even if medical intervention in a fully-functional hospital would have made little difference, the hospital and physician may be found liable, either in court, or in the news media.

Other factors that would begin to create major operational challenges in an extended outage would play major roles in the capacity of the hospital to treat the wounded. In Southern California, air conditioning is essential for a health care facility for most of the year. Beyond patient comfort, a lack of air conditioning would massively increase staff fatigue, and perhaps contribute to equipment failure in sensitive equipment. Another factor often overlooked is the importance of operational elevators. Given the tower design of NHMC, and the fact that the three towers that are home to acute care treatment facilities are designed to separate in an earthquake, elevators are an essential component of patient treatment and care.

After the Northridge earthquake, NHMC was without power and water for approximately four days. The facility was damaged, as noted, 3 towers actually separated due to the force of the shaking. The EPSS system operated as designed, and emergency power was restored within 10 seconds of the outage. Onsite engineers and hospital administrators made the decision to occupy the building based on the performance of the structure and the preliminary data available regarding the severity of the ground motion.

Capacity to Adapt after a Disaster

The Hospital Emergency Incident Command System (HEICS) is the cornerstone of post-event emergency planning at NHMC. HEICS was originally developed in California, but its use is widespread in North America. HEICS essentially activates an emergency command system, links the hospital emergency planner with community's emergency response command, activates staff to pre-assigned secondary HEICS duties, and makes available a range of medical supplies and equipment held for exclusive use during a HEICS incident.

NHMC has invested substantial planning efforts in incorporating HEICS procedures into the daily operational life of the hospital. For example, so-called "bed meetings" are held throughout the day where hospital staff from the ED, ICU, wards, and administration meet to determine the capacity of the hospital in real time. During a HEICS, this meeting would be automatically called and the facility could quickly establish its operational capacity and communicate this data to the local emergency command.

Based on NHMC's experience during the Northridge earthquake, and similar experiences at other hospitals worldwide, NHMC's security staff has also been incorporated into the HEICS. If an emergency is declared, security staff are assigned to control the perimeter of the hospital and establish 1 entry/exit point in order to facilitate effective triage and maintain the hospital's ability to provide care. This may be essential in the darkened aftermath of a large earthquake if the hospital faces a surge of injured patients demanding medical care. If the facility cannot maintain security and order, it is unable to offer efficient medical services. For example, under emergency power conditions and a surge of injured victims arriving at the hospital, plans must be made on how to deal with uninjured family members accompanying the injured, as many of the hospital's non-critical areas such as waiting rooms will be un-powered.

HEICS has also demonstrated itself to be capable of adapting to new demands place on the hospital by the cascading nature of failures in the healthcare system. Beyond the impacts on the facility itself, power outages trigger unexpected demands for care. During one outage at NHMC, an intermediate care provider called to inform NHMC staff that that facility was evacuating, and asking if NHMC could accept that additional patients. This decision required a quick response, and had significant repercussions for the facility and the patients involved. If NHMC was unable to accept that patients, it would have been compelled to close the facility to any new patients under a state law that restricts hospital's ability to refuse care to emergency patients. NHMC was already operating on emergency power and near capacity. By calling on the staff involved in the daily 'bed meetings', the staff was able to make arrangements to handle the influx of patients and keep the facility open. The capability to maintain coordinated, multiple-stakeholder decision-making capacity through the HEICS proved critical to the facility's ability to adapt and manage its resources during this emergency to provide care to the community.

In addition to the HEICS, NHMC also participates in community-level coordination of emergency preparedness in hospitals. While NHMC is a regional trauma center, in a disaster, the Henry Mayo Hospital Newhall Memorial Hospital acts as a "disaster resource" hospital to provide assistance during disasters, medical supplies, and accept transfer of patients requiring advanced care. In order to participate in this program, NHMC also had to complete a vulnerability analysis. The analysis, based in large part on lessons learned from the Northridge quake, identified priorities, and further mitigation efforts needed in order to achieve compliance with SB 1953. In pursuit of SB 1953 compliance, NHMC has a full-time staff member dedicated to implementing programs designed to achieve SB 1953 compliance. However, the planning task is "overwhelming" and in spite of the fact that Los Angeles County is considered one of the most disaster prepared counties in America, the county is unable to assist NHMC in an emergency, making its operation wholly contingent on effective emergency planning and vulnerability reduction.[198]

In spite of advanced preparations, the Northridge earthquake caused several disruptions to power and water supplies that required unplanned, adaptive responses. Immediately after the earthquake, NHMC was thrust into darkness and without water. Communications were severely restricted with the loss of telephone lines and emergency communications equipment onsite at the time proved inadequate. An effective response to water outages was made possible by two fortunate aspects of the facility's design and location. First, NHMC operates a swimming pool used in patient rehabilitation. The hospital engineering team was able to use the water stored in the pool to meet sanitation needs and toilets. Potable water was delivered from the nearby Anheiser-Busch beer factory located nearby the hospital. Without the water from the pool to maintain sanitation and potable water to supply staff, patients, and provide water for medical procedures, it would have been extraordinarily difficult for NHMC to maintain operations. The reliance on water supplied by tanker trucks is ample evidence of how emergency plans are contingent on a functional transportation network.[199]

[198] Susan Shanbam Ibid.
[199] Susan Shanbam Ibid.

Personnel resources were also a major challenge in the aftermath of the Northridge Earthquake. Callback lists were used to locate staff and ensure personnel were available to relief staff onsite at the time the earthquake struck. While helpful in the Northridge earthquake, callback lists have been augmented with established protocols for responding to different types of disasters. However, NHMC remains highly vulnerable to a particularly intractable human resource problem: physician staffing during an emergency. In short, according to a hospital official, “We don’t think our physicians will come to work.”[200] Most physicians at NHMC are not employees of the hospital except for residents and ED physicians. If offsite physicians do not report to support the hospital during an emergency, NHMC’s medical capacity will be seriously reduced. Thus, emergency plans must consider carefully the ability to reduce the demand for non-essential medical care. In the Northridge case, it was necessary to evacuate some patients. (Mostly newborn babies and their mothers after the nursery became isolated from the maternity ward when the towers separated.) The hospital also discharged as many patients as possible, which during the Northridge event, was sufficient to continue offering emergency and essential medical care to the community.

NHMC also learned important lessons about developing and implementing its emergency plan. The changes are best described as incorporating emergency planning into the everyday operations of the facility. For example, officials from all departments and administration meet twice daily to conduct a ‘bed count’ meeting where current capacity is determined and plans made to discharge some patients and admit others. Thus, critical resources such as ED and ICU beds are managed. This distributes the information throughout all decision-makers in the hospital and ensures that should an emergency strike, these decision-makers have a ‘snapshot’ of the hospital’s capacity before the emergency occurred. For strategic emergency planning, NHMC convenes an Emergency Preparedness committee that meets monthly. The committee consists of ED officials, EMS operators, security, and other interested personnel.

[200] Susan Shanbam Ibid.

The goal of the committee is to ensure compliance with state regulations concerning emergency planning and to ensure that NHMC emergency plan is well-understood within the hospital community. While this committee demonstrates involves a broad range of stakeholders, it lacks public participation. This has not been possible for a number of reasons, but most importantly, it is not clear if there are members of the community interested in serving on the committee, and second, there are concerns over protecting confidentiality of information.

In summary, NHMC represents a case study that demonstrates the potential for "rule-making" models of decision-making in creating incentives for effective emergency preparedness. Built to, or in exceedance, of standards relevant at the various times that facilities were constructed, the hospital weathered adequately the challenge of the Northridge earthquake. Currently, the hospital is attempting to adapt its preparedness to two, potentially competing, paradigms in emergency preparedness, SB 1953 on the one hand, and terrorism on the other. While both of these mandates ought to contribute to improved emergency preparedness, hospital administrators acknowledge that the secrecy and security necessary for preparation for potential acts of radiological or biological attacks conflict with past operating norms in emergency preparations. The other aspect of this dilemma is that planning for terrorist attacks focuses mainly on treating a surge of emergency patients, and securing and limiting the extent of facility contamination. As such, this type of emergency preparedness is similar to past efforts that de-emphasize the potential of the hospital site itself to become the locus of disaster. A direct result of the dual focus of the emergency planning effort at NHMC has been that planning staff face an almost overwhelming challenge. Thus, longer term objectives that will increase the facility's resilience such as linking with neighbouring facilities, or partnering with facilities outside of Los Angeles County to coordinate patient evacuation or staff relief plans have not been pursued at this point.

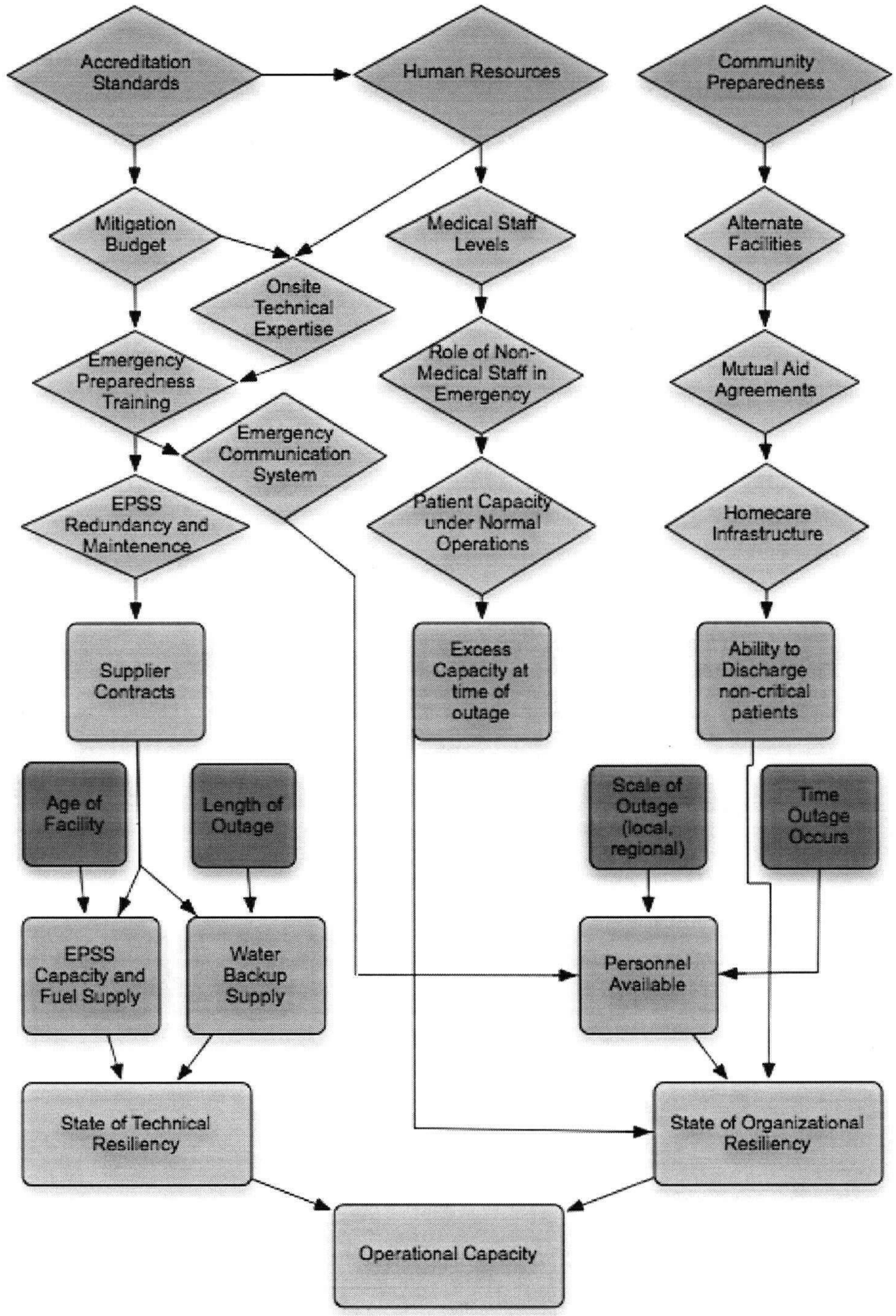
Chapter Five: Analysis

5.1 Decision Analysis and Mitigation

In general, hospitals in all of the case study areas consider similar factors in making decisions about disaster mitigation and reducing the impact of power and water outages on their facilities. Thus, the following influence diagram in Figure Twelve outlines visually the decision context and explains some of key factors that influence decisions and variables indicated by the diagram.

The diagram is colour-coded to assist in its interpretation. The brown colours indicate decisions that lie outside the immediate scope of hospital decision-makers. The green boxes indicate decisions that fall under the purview of planners and administrators at the facility level. The purple boxes indicate outcomes that are influenced by the decisions made at both the facility level and other levels. The red boxes indicate variables that lie outside of the control of, and not influenced by, decision-makers. The age of the facility has been included in this category because while it is possible to simply reconstruct a newer facility, this is generally not feasible nor desirable. Last, the green boxes indicate the results of the interaction between the decisions made and random variables on the operational capacity of the hospital.

Figure Twelve: Ex-Ante Influence Diagram



Influence Diagram Legend

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

A. External Decision: Accreditation Standards

Decisions about Accreditation Standards, in general, lie outside the direct influence of individual hospitals. In order to fulfill their core mission, hospital's must comply with standards established by the relevant accreditation organization. (CCHRA in Canada, JCAHO in America.) Consequently, decision-making about risk mitigation exhibits many of the satisficing decision outcomes associated with the Rule-Following model of decisions.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

A1: Decision: Mitigation Budget

Decisions about financing mitigation activities is one of the most important decision in terms of determining the hospital's vulnerability to power and water outages. In general, decisions are based on meeting accreditation standards, and responding to incidents that may have occurred in the hospital on an ad hoc basis. One of the key opportunities for improving decisions about risk mitigation is to better understand the benefit-cost relationship of mitigation and to fund mitigation projects through stable budget allocations, rather than on an ad-hoc project based model.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

A2: Decision: Onsite Technical Expertise

Hospitals are home to a vast array of complex systems and equipment, EPSS systems are increasingly complex, requiring advanced knowledge to operate, maintain, and trouble-shoot when necessary. Hospital administrations need to make choices about the level of expertise onsite versus the cost of that expertise.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

A3: Decision: Emergency Preparedness Training

The resiliency of a hospital facility will depend greatly on the ability of hospital staff to function effectively under EPSS conditions. Staff need to know how to triage patients for care under emergency conditions, minimum standards, back-up procedures for patient-care documentation amongst many other operational changes. It is critical to provide funding for regular training and emergency drills.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

A4: Decision: Emergency Communication System

Investment in effective, and redundant, emergency communications systems is critical for effective emergency operations. The ability to coordinate the hospital response, internally and externally, is essential. Communications also provide an essential tool to manage demand under emergency conditions, thus making them essential to a facility's technical resiliency.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

A5: Decision: EPSS Redundancy and Maintenance

The design, maintenance and testing protocols of the EPSS are essential aspects of technical resiliency. Crucial choices such as one large capacity generator versus several smaller generators and the capacity of the emergency power compared to regular power will greatly influence the hospital's vulnerability to power outages.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

A6: External Chance Node: Supplier Contracts

Given their complexity, is virtually impossible for a modern hospital to be technically self-sufficient. EPSS equipment vendors play an important role in implementing the EPSS. Hospitals are dependent on the ability of vendors to provide spare parts, repair and operational supplies such as fuel during an emergency. Thus, if transportation or communication infrastructure were severely impaired, it may prove impossible for vendors to honour these contracts, rendering the EPSS in-operational.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture. A7, A8 Variables

The age of the facility will have a substantial impact on the reliability of the EPSS systems and other equipment. Facility age will also impact decisions about investing in further mitigation. While there is evidence that suggest investing in new facilities is cheaper than upgrading old ones, this is a difficult and time-consuming process. The length of the outage will also seriously impact the technical resiliency of the facility. Longer outages will cause more problems with equipment reliability and re-supply of fuel.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

A9: Internal Chance Node: EPSS Capacity and Water Supply

The result of decisions made at the strategic level (accreditation) and operational levels, combined with variables such as the age of the facility and length of the outage will determine the operational state of the EPSS and back-up water supply.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this pictur A10: Consequence Node: State of Technical Resiliency

The state of technical resiliency describes the ability and operational capacity of the facility to maintain operations. It is a relative state that is defined in relationship to 'normal' supply of power and water to the facility. Thus, 100% technical resiliency means that the facility is fully operational indefinably. The relationship between impaired capacity and time to restore capacity is described in Figure Four.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

B: External Decision: Human Resources

Decisions about human resources lie largely outside the decision-making context of the emergency planner. While engaged in the process, hospital administrators do not fully control the human resources budget and must respond to these directives. Finally, even without financial constraints, there is a North American wide shortage of medical personnel such as nurses.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

B1: Decision: Medical Staff Levels

As noted, budgetary constraints are important factors in staff levels. However, the hospital, in accordance with accreditation guidelines, can allocate staff based on its primary mission. For example, if could reduce the number of night medical staff to minimum levels in order to have more staff on-site to improve out-patient treatment during the day.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

B2: Decision: Role of Non-Medical Staff in Emergency

With advanced planning and training, non-medical staff such as hospital administrators and support staff could provide vital assistance to medical staff. Examples include assisting ventilate patients in total power outage, supporting medical record keeping, and re-locating patients if necessary.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

B3: Decision: Patient Capacity under Normal Operations

In the facilities researched for this thesis, staffing, as opposed to physical space, was often the primary factor limiting operational capacity. Therefore, decisions about preserving the physical 'slack' within the physical environment of the hospital may prove to be important in adapting capacity to respond to power and water outages.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

B4: Internal Chance Node: Excess Capacity at time of outage

The impact of the outage will depend greatly on the excess capacity (slack) within the hospital. This varies greatly over the year, even reflecting seasonal variances. (e.g. fewer surgeries in the summer due to medical staff vacations) While influenced by the decisions made in B-B3, the natural variation in capacity utilization may mitigate or amplify the impacts of power and water outages.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

B5, B6: Variables: Time Outage Occurs and Scale of Outage

Most hospital emergency plans for power outages are based on them minimum staff onsite at the time of the outage. (e.g. 2am) An outage at this time would have vastly different consequences than one occurring during the day when the facility is operating at higher capacity. Moreover, the nature of the emergency will be vastly different. At minimum staffing levels, patient demands are lower, but spread across fewer staff, and few administrative officials on site. During the peak hours of the day, more staff are on hand, but the scope and complexity of the problems resulting from the outage may be amplified. The scale of the outage will also have significant influence on the capacity of the hospital to continue operations and recover to full capacity. If only one facility is affected, the hospital could evacuate patients to other facilities with relative ease, relieving the demand, and enabling a gradual return to operations. However, if the outage is regional and evacuation of patients is not feasible, the facility will need to continue to meet the needs of its patients while simultaneously struggling with recovery operations.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

B7: Internal Variable: Personnel Available

This variable reflects the outcomes of choices made in earlier decisions and the influence of random variable relating to the outage itself.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this pictur

B8: Consequence Node: State of Organizational Resiliency

Organizational resiliency refers to the ability of the hospitals personnel to respond and manage the power outage. It also considers how adaptation and response to EPSS conditions will impact the overall resiliency of the hospital.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

C: External Decision: Community Preparedness

Community preparedness is a crucial factor in the resiliency of hospitals. First, hospitals are dependent on a vast array of infrastructure such as transportation and communications to name only two. Second, by working with the community, it will be possible for the hospital to better coordinate its response to power and water outages and leverage other community assets, and work with the public to reduce demand for healthcare when hospital capacity is tight.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

C1: Alternate Facilities

Planning alternate sites is an essential component of hospital resiliency. Hospitals need to identify in advance partner hospitals that might serve as alternate sites for patient care. Hospitals must also work to identify and prepare non-traditional sites such as parking lots or neighbouring open-space that could be transformed into an emergency care facility. Beyond the site level, it is important to create plans to implement and staff temporary emergency hospitals that could be located in public buildings such as schools or community centres.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

C2: Mutual Aid Agreements

Hospitals need to identify in advance partner hospitals that might serve as alternate sites for patient care. These arrangements could take a number of forms such as partner hospitals outside the region (possible evacuation) to technical and personnel assistance agreements wherein personnel from other hospitals could relieve staff at the affected hospital.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

C3: Homecare Infrastructure

Community homecare has been increasingly emphasized as an effective way to reduce healthcare costs and provide care. Emergency planners need to consider how homecare assists in dealing with emergencies (fewer patients onsite) with how it may pose additional challenges during emergencies. (power dependent homecare patients requiring access to power and care at hospital site during a power outage.)

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

C4: Ability to Discharge Non-critical Patients

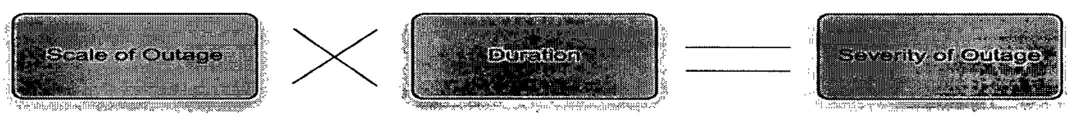
The ability to discharge non-critical patients during a power outage is contingent on a number of factors. It involves standards of care related to accreditation standards, hospital policies, medical evaluation, and the ability to meet the needs of discharged patients in other settings. If significant numbers of patients cannot be discharged, the hospital may struggle to deal with the power emergency.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this pictur B, C: Consequence Node: State of Organizational Resiliency

Organizational resiliency refers to the ability of the hospitals personnel to respond and manage the power outage. It also considers how adaptation and response to EPSS conditions will impact the overall resiliency of the hospital.

In determining the appropriate level of preparedness, emergency planners must consider the threats they face. A vulnerability analysis is one approach to characterizing the risks and vulnerabilities facing planners. While vulnerability analysis are unique to each facility, vulnerability to a power and/or water outage can be defined as follows in Figure Thirteen.

Figure Thirteen: Determinants of the Severity of Power and Water Outages



However, based on the seismic threat facing each region in the case study, and comments made by emergency planners, the seismic threat is viewed as the most significant threat in terms of causing prolonged power and water outages. Defining the likely intensity of an earthquake is a massively complex, inexact, science. A host of variables, both known and unknown, act in concert to produce the intensity and impacts of an earthquake. A cursory list include location of the epicenter and depth (focus), magnitude, length of the shaking, soil types, time of day, quality of buildings in region, population density, quality of infrastructure, and the extent of emergency preparation and planning. Obviously more variables could be added to this list; the point however is to acknowledge the enormous uncertainty in both the intensity of an earthquake and a region's vulnerability to that intensity. The notion of seismicity, discussed in the Vancouver case study, indicates some of the progress science has made to reduce the uncertainty surrounding probable seismic events. However, the spatial and temporal elements of these estimate of recurrence do not yet provide a realistic warning system, thus emergency planners must carefully consider the intensity of the event which they are preparing for. In most cases, the maximum intensity of an earthquake is codified for a region known as the maximum probable earthquake (MPE). Typically, MPE figures indicate a maximum intensity earthquake from which "shake maps" are produced that approximate the local intensity of the shaking based on proximity to the probable focus of the earthquake and local soil conditions. In California, the MPE includes a 10% chance of exceedance within any fifty-year period.[201] (in British Columbia, under proposed CSA standards this threshold would be reduced to 2%) Clearly, decision-makers face great uncertainty in how they respond to scientific data that outlines the seismic hazards for their region.

However, in determining the severity of the earthquake planners ought to prepare for, it is possible to narrow the range of uncertainty in the science. The intensity of earthquakes is commonly measured in two ways. The first, and most commonly reported, is the Richter Scale. This scale measures the magnitude of an earthquake, and each one-tenth increase corresponds to a ten-fold increase in the amplitude of the shaking. Thus, while it is an accurate measure of the energy released by an earthquake, it is often difficult for the public and planners alike to understand. The first problem with the Richter scale is that while a M6.0 earthquake may not sound all that difference from a M5.5 quake, the difference in the energy released, and thus potential for damage, is substantially different. Second, the Richter scale does not incorporate how the distance from the focus (depth and location of the earthquake on the surface of the earth) reduces the amplitude of shaking. For example, on March 31, 2002, a M6.8 earthquake occurred 175km away from Taipei. While the epicentre of the quake is located off Taiwan's east cost, Taipei's distance from the epicenter of this quake is similar to its distance from the Chi-Chi quake's epicentre. Yet the outcomes of

[201] ABS Consulting, "Earthquake Risk Management: A Toolkit for Decision Makers" Accessed: Sept 10, 2003 http://www.eqe.com/revamp/pdf/toolkit/cssc-3a.pdf

the two events were profoundly different; the March 31 event, while still serious, was significantly less damaging to structures in Taipei. For this reason, Richter scale measurements are often accompanied by the Modified Mercalli Intensity Scale (MMI). The MMI, while less widely reported than the Richter scale, provides arguably a better indication of the severity of the earthquake in a local area because it reflects the intensity of the shaking and the potential for that shaking to cause damage. MMI can also reflect local variation such as soil types that may amplify or attenuate the shaking.

The use of these scales enables decision-makers to better understand the seismic threat to their facility. First, using the Richter scale, one can eliminate roughly 99% of earthquakes from one's vulnerability analysis because only an estimated 1% of earthquakes annually exceed M5.0, a magnitude widely considered the threshold for the potential for serious damage. Figure Ten records the estimated 1084 earthquakes annually with a magnitude great enough to cause damage.[202]

Table Six: Annual Average Global Earthquakes Greater than M5.0[203]

Destructive Richter Magnitudes	Effects Near Epicenter	Estimated Number per Year
5.0-5.9	Damaging Shocks	800
6.0-6.9	Destructive Populous Regions	266
7.0-7.9	Major Earthquakes; inflict serious damage	18
>8.0	Great Earthquakes; cause extensive destruction near epicenter	1.4

[202] Brunious, Courtney and Amanda Warner "Earthquakes and Society" Available online at: http://www.umich.edu/~gs265/society/earthquakes.htm
[203] Brunious, Courtney and Amanda Warner

The MMI adds important information about the local intensity of the earthquake. MMI ranges across twelve levels of intensity. For the purpose of emergency planning, it is only necessary to consider MMI figures of V and greater, the effects of which are noted in Table Seven.

Table Seven: Modified Mercalli Intensity Scale: Destructive Intensities[204]

MMI	Effects
V	Felt by nearly everyone, many awakened. Disturbances of trees, poles and other tall objects sometimes noticed.
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. (Fall of chimneys, factory stacks, columns, monuments, walls.)
IX	Damage considerable in specially designed structures. Buildings shifted off foundations. Ground cracked conspicuously.
X	Some well-built wooden structures destroyed. Most masonry and frame structures destroyed. Ground badly cracked.
XI	Few, if any (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground.
XII	Damages total. Waves seen on ground surfaces. Objects thrown upward into air.

[204] Tarbuck, Edward J and Frederick K. Lutgens. Earth: An Introduction to Physical Geology. Prentice Hall: New Jersey, 1996

Poignantly demonstrating the importance of considering MMI intensity in emergency planning, according to Taiwan's local intensity scale (which ranks intensity from 1-7 but in other respects is very similar to MMI) the 2002 M6.8 earthquake created Level 5 intensity,(approximately MMI VIII) while the Chi-Chi quake produced Level 4 intensity(approximately MMI VII) in Taipei City.[205][206] While both measures have positive and negative attributes, it is important for emergency planners to emphasize MMI intensity for several reasons. First, as MMI records the degree of shaking locally, it is more likely to accurately represent the vulnerability of the facility to the shaking that results from an earthquake. Second, individuals respond to the perceived level of shaking. Typically, based on the author's experience, in the immediate minutes after substantial shaking public communication networks are quickly overwhelmed by a surge of demand as residents attempt to make calls to check on the well-being of loved ones. Second, substantial shaking also create stress and fear. Thus, not only does the physical risk of injury increase with the intensity of shaking, the psychological impacts to do so as well. It is hypothetical, but reasonable, to assume that with greater shaking intensity greater demand for healthcare from victims of this stress (e.g. heart attack) is possible. Third, staff and patients will also be experiencing stress from the shaking. These factors all mean that a functional emergency plan that deals with these factors, in addition to the potential for power and water loss, be prepared to deal with the local shaking intensity that might be expected from a region's MPE.

Already, a great deal of support from the scientific and engineering communities is offered to decision-makers in responding to the seismic threat they face. Clearly, emergency planners are focused on earthquakes with the potential to damage facilities. However, in order better understand how to apply the scientific data regarding the threat it is essential that decision-makers understand how to apply measurements such Richter scale and MMI in their

[205] Department of Medical Informatics College of Medicine, National Taiwan University "21 [illegible]" (in Chinese) 2000 Available online at: http://www.mc.ntu.edu.tw/staff/cmrg/921review/review.htm

[206] Chinese Christian Relief Society, "**331** [illegible]" (in Chinese) Available online at: http://www.ccra.org.tw/relief/Functioncode/Publish/focusfindshow.asp?sn=774&type=1

planning decisions. This will avoid several heuristics that frequently paralyze decision-makers and lead to either paralysis of action because of the erroneous belief that nothing can be done, or alternately, the over-confidence represented by terms such as 'earthquake proof' buildings. Understanding the potential magnitude of earthquakes and the organization goals for building performance after an earthquake leads to three distinct levels of preparation: life safety, post-disaster serviceability, and business continuity illustrated in the following decision-trees. According to Jay Lewis, a seismic retrofit engineer, life safety standards are designed to ensure that occupants of the building are not killed by a structural collapse of the building or falling objects. Post-Disaster and Serviceability is a higher standard of mitigation that aims to protect occupants and equipment, requiring only minor repairs before fully-regaining operational capacity. In general, this standard aims to ensure operational readiness within 72 hours of the event. The highest standard of earthquake mitigation is Business Continuity, which, if effective, would allow a facility to continue to operate a pre-disaster capacity. Each decision tree includes a random variable that indicates if an earthquake occurred or not. For the purposes of these diagrams, the magnitude and intensity of the hypothetical earthquake is assumed to be the MPE for that region (from which design codes are also based).

Life Safety

Life safety represents minimal hazard mitigation. Essentially, its aim is to ensure the building survives the earthquake without causing injury to its occupants either through building failure or falling equipment. After a serious earthquake, a facility with only life safety would not likely be able to operate, and in fact, would most likely be abandoned. While this standard may seem basic, many hospitals in seismically vulnerable regions do not meet even this standard. Moreover, depending on the region, life safety can have very different meanings. For example, the current applicable building code for life safety in the lower mainland region is known as NBCC-1995 (National Building Code of Canada). Even compliance with this code does not guarantee the life safety of a structure, as the design code includes a 10% probability that the forces of an earthquake will exceed the design standards within any fifty-year period.[207] The NBCC-1995 code is currently under revision, and the NBCC-2005 code is expected to include only a 2% possibility of exceedance in any fifty-year period. Thus, planners must be aware of what this standard actually means, and that compliance with the NBCC-1995 code means that there is a significant degree of uncertainty in regard to the ability of the structure to provide life safety during an earthquake. Moreover some studies have found that "major components of emergency power systems were generally adequately anchored and braced for moderate level seismic events. . . .System logic, maintenance, and periodic test programs should be improved to ensure reliable performance following earthquakes. ... Emergency power systems should be a priority issue for further research."[208] Thus, it is clear that one cannot assume that most hospitals in 2005 in the study regions already comply with life safety mitigation standards. Figure Fourteen illustrates the potential outcomes that might result from a decision to mitigate to this standard or not. A larger version of the document can be found in the appendix.

The decision tree represents a schematic view of the likely alternatives, with no attempt made to assign probabilities and thus calculate the expected utility resulting from different choices. Moreover, the outcomes are described in general terms, and the desirability of the outcomes is colour-coded, ranging from blue (no earthquake), green (most desirable outcome of mitigation), orange (unsatisfactory result) to red (severe impact). In general, the characterization of these outcomes is based on expected outcome to the hospital's ability to function as measured by its patient capacity.

Figure Fourteen: Life-Safety Mitigation Decision Tree

[207] Onur, Tuna, Carlos E. Ventura and W.D. Liam "Effect of Earthquake Probability Level on Loss Estimations" Presented at: 13th World Conference on Earthquake Engineering, August 1-6, 2004 Paper No. 2608 Available online at: http://www.seismo.nrcan.gc.ca/hazards/13wcee/13WCEEp2608Onur_etal.pdf

[208] Spectra, 2001 p. 283

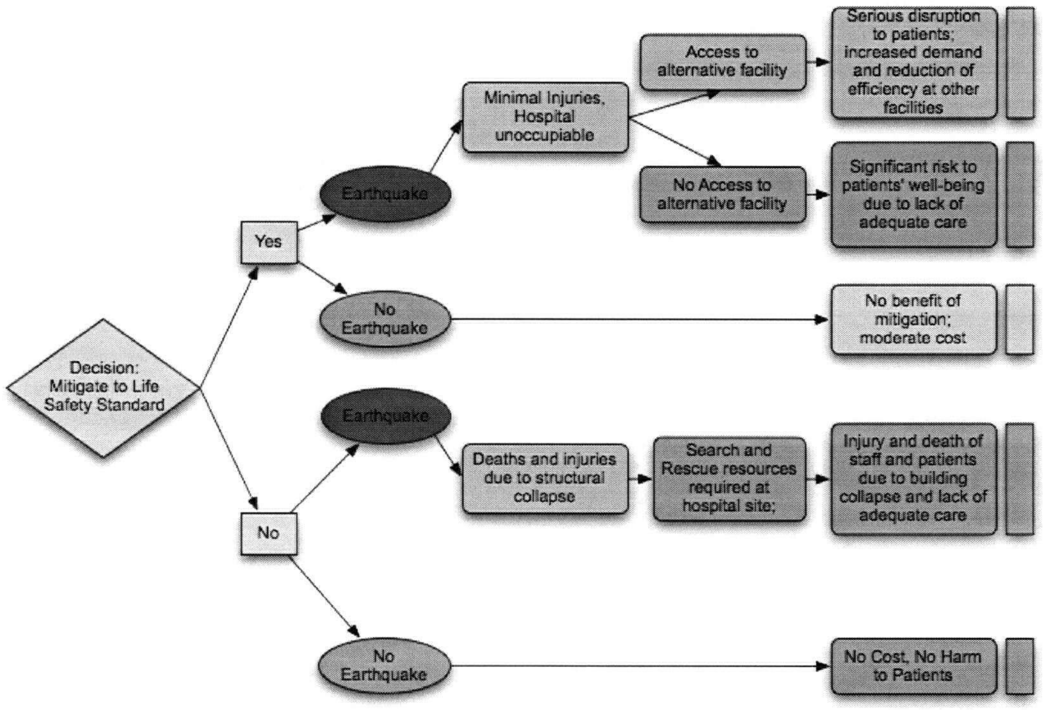


Figure Fourteen illustrates the paradox of decision-making in terms of risk mitigation for seismic hazards. Given the time frame of most decisions, the 'rational' choice for the decision-maker is to choose not to mitigate. The reason for this is obvious; the probability that a large earthquake will occur during in the time frame of most decision-makers is low. Thus, a decision to not retrofit to life safety standards could produce the outcome of no cost and no harm to the facility. Yet, this choice is flawed for several reasons. First, based on the case studies in this thesis, it is clear that hospitals in areas that have experienced large earthquakes in recent memory have taken more steps toward mitigation than hospitals without this experience. However, geologists argue that in seismically active areas, the longer the period of time without a large earthquake likely means that such an earthquake is *more* likely, not less. It is likely that decision-makers have difficulty internalizing this information in their decision-making process for two reasons:

i. The Availability Heuristic: Planners who have not experienced a significant earthquake are more likely to underestimate the likelihood of this event occurring.

ii. Misconceptions of Chance[209]: Seismic risk is often communicated in terms of seismicity levels. Seismicity levels are calculated using the probability of a certain magnitude event occurring within a specified time frame. This information is then communicated in seismic hazard maps or forecasts such as "a 60% probability of an earthquake of magnitude 6.5 Richter scale in the next 30 years." Decision-makers often misunderstand the connection between the probability and the time frame and errantly believe the earthquake is more likely to occur toward the end of the time frame. This is incorrect. The probability of the earthquake happening is equal at any given point. Thus, a earthquake that is expected to occur within a 100 year time period is just as likely to occur today as it is 99 years from now.

Overcoming these factors in poor decision-making means engaging in a sustainable approach to mitigation that requires planners to embrace the concept that events such as earthquakes *will* happen. Because science has not advanced to the point make accurate prediction possible, the only mitigation available to communities and hospitals is to prepare for them, which means, at the very least, ensuring compliance with life-safety design requirements for all public buildings, and especially hospitals, where many of the occupants cannot evacuate a heavily damaged structure.

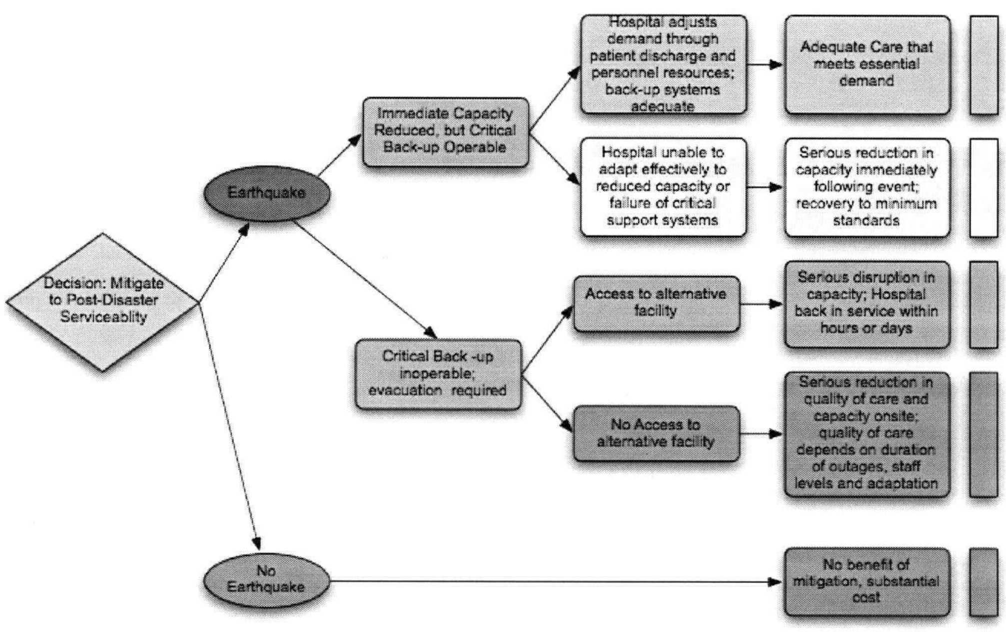
Post-Disaster Serviceability

Post-Disaster Serviceability standard means that a hospital, and its equipment, can function immediately after an earthquake. Current legislation

[209] Bazerman, Max Judgment in Managerial Decision Making Fourth Edition, Wiley, 1998 p. 21

such as California's SB 1953 and Canada's upcoming NBCC-2005 are examples of design codes that are intended to offer this level of functionality. Decisions to upgrade preparedness to this standard can only be taken once structural considerations have been taken, since non-structural mitigation is futile if the building fails. Consequently, the decision tree in Figure Fifteen does not reflect the choice not to mitigate to post-disaster and serviceability standard. Again, a larger version of this diagram can be found in the appendix.

Figure Fifteen: Post-Disaster Serviceability Mitigation Decision Tree

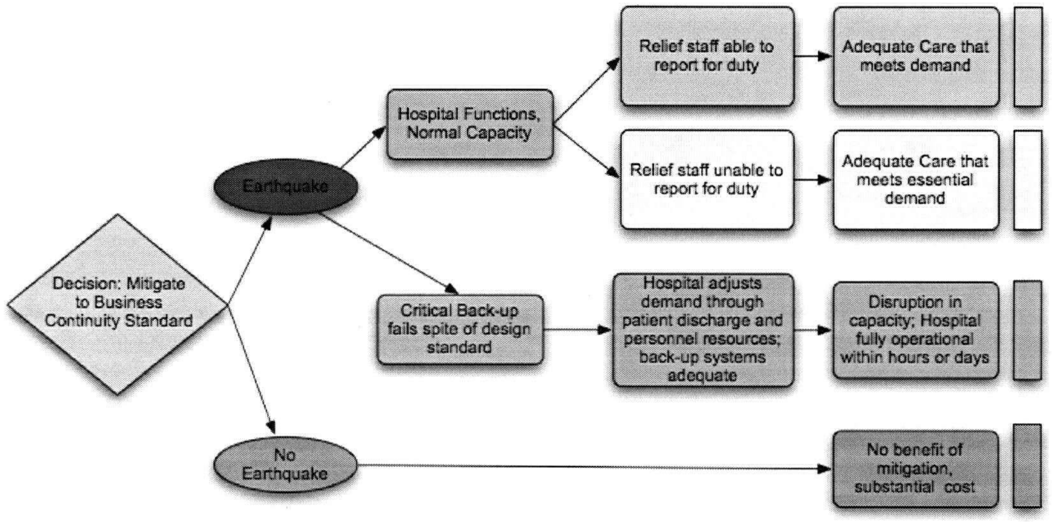


This decision tree illustrates another key aspect of decision-making. Only one of the four possible outcomes results in a desirable (green) outcome. A successful outcome of the mitigation effort requires that all systems perform as designed and staff have the ability to quickly adjust hospital capacity to a reduced power regime by discharging patients. If hospital staff is unable to do so, it is possible that patient care and capacity will rapidly decrease as back-up power systems such as EPSS are over-taxed or fail. This emphasizes the need for effective planning and decision-making both before and after a disaster. Ex-ante decision making requires new directions as discussed under Life Safety mitigation, but also requires better planning for ex-post adaptation.

Business Continuity

A Business Continuity mitigation standard is the most elusive standard in terms of technical requirements, planning, and implementation. If implemented successfully, a business continuity mitigation standard would enable a facility to continue 'business as usual' during a major outage, regardless of cause. This standard is already in place for facilities such as nuclear power plants, most major Emergency Operations Centres (EOCs), and critical government command and control centres. Past disaster experience illustrates the need for key medical facilities to maintain operational capacity ex-post. Figure Sixteen illustrates some of the outcomes that may result from a decision to mitigate to this standard.

Figure Sixteen: Business Continuity Mitigation Decision Tree



Evidently, a decision to mitigate to business continuity standards is far more likely, but not certain to, produce the desired outcome of ensuring hospital capacity under power and water outage scenarios. Thus, for the decision-maker the decision to mitigate to a business continuity standard holds two risks. The first, is that no earthquake occurs, rendering the benefits of the mitigation invisible. The second is that should an earthquake occur that exceeds the design standards the hospital administration might be blamed for profligate spending on ineffective mitigation activities. Again, overcoming short-term views requires broadening the decision choice from simply mitigation to improved healthcare. Officials responsible for emergency management at hospitals have emphasized that the most effective mitigation measures also improve regular operations at their facility. Thus, with adequate financial support to make the initial necessary investments, new operational efficiency may offset some of the costs of mitigation. An example of this is that according to one knowledgeable source, constructing a new hospital to this standard should only add 2-3% to the total cost of the facility.[210] Moreover, on almost any measure including cost-effectiveness, if a decision-maker *knew* in advance that a seismic disaster would occur, he or she would surely chose to prepare for it by designing to this standard. Given the seismicity of the three regions considered herein, it is unreasonable to assume that a disaster will not happen. Clearly, the decision will in some cases be made for communities. We can prepare key facilities now in preparation for a potential disaster, or, we can wait until after the disaster to rebuild facilities to this standard. The collective failure of communities to invest in disaster resilient hospitals indicates that communities either accept implicitly the consequences of this lack of thorough preparation or chose to ignore their vulnerability. The efforts of planning professionals working in hospitals, the efforts of engineers, academics and others, and the work of the political community in legislating change indicates there is a strong desire to realize the vision of disaster resilient hospitals. Hospitals, as the focal point of a community's emergency response, and a potent symbol of either hope or despair in the face of catastrophe, ought to form the basis of planning and realizing disaster resilient communities.

[210] Jay Lewis, ibid.

Chapter Six: Conclusions and Recommendations

6.1 General Findings

Question One: How would water and power outages affect hospital service and capacity?

The fundamental research question of this thesis was to ascertain the impacts of power and water outages on hospitals. The answers are complex, and depend on a number of factors. The simplest answer is the most obvious: without power and water a hospital is figuratively, and quite possibly, literally, "out of business."[211]

In spite of its obvious simplicity of this answer and the catastrophic consequences, it is apparent that many decision-makers discount the likelihood of a total outage occurring in their facility. Instead, almost total faith is invested in the efficacy of existing measures such as EPSS systems. The case of water outages is even more troubling, given that hospital officials indicate a total absence of potable water would have greater impact than a total power outage, hospitals have yet to invest in on-site water back-up capability, and instead rely on third-party suppliers or government agencies to provide back-up. Clearly, the Chi-Chi earthquake and the experiences of hospitals there indicate that total power and water outages *can* occur. That experience also demonstrates the extreme difficulty in restoring power and water, or creating alternative emergency care facilities during the critical first 72 hours of a disaster.

Beyond the potential for a total loss of capacity due to power and water outages, characterizing reduced operational capacity due to extended reliance on EPSS and back-up water is difficult. What is known however is that while extended operations under this scenario are possible, and the efficacy of the back-up systems is likely to decline rapidly with time. Issues such as fuel supply for the EPSS, water replenishment, and ongoing operation of generators and

211 Jay Lewis, Ibid.

crucial switch equipment limit the ability of hospitals to function during an extended outage. Moreover, cascading impacts due to failure of communication and transportation networks is likely to exacerbate the impact on hospitals capacity. Even if power and water supplies are maintained, depletion of critical medical supplies and staff resources may force facility evacuation or capacity reductions. These contingencies are related to the power and water outage because suppliers would be impacted by the power failure and may not be able to maintain their just-in-time delivery capacities. It is critical to keep in mind that few jurisdictions have experience in dealing with these types of problems, and to date, those that have, have generally failed to perform at a satisfactory level. (Taiwan, Chi-Chi, United States, Hurricane Katrina)

Increased mitigation and preparedness standards such as those mandated by SB 1953 in California or changes in building codes will increase the ability of hospitals to function post-disaster. However, the experience in all three regions considered in this study indicate the long time lag between adoption of new standards and their implementation through new facility construction and retrofitting projects. At this stage in emergency planning for hospitals, resilience is based on a somewhat ad-hoc legislative environment where the majority of facilities do not comply with existing standards, and even in the most ambitious plan (California) are not required to do so for another twenty-five years. In the short-term, it appears unrealistic that to assume that society is willing to make the financial commitments necessary to substantially reduce the vulnerability of hospital facilities to power and water outages. Given this, decision-makers need to consider alternate approaches to reducing a community's vulnerability to losing its healthcare services in the aftermath of a major disaster. For example, if hospitals could maintain power, water, supplies and staff during the first 72-hours of the disaster, and during that time, emergency hospitals could be set-up, the overall capacity of the healthcare system to respond to the immediate impact of the disaster and quickly recover operational capacity would be increased as the temporary facilities take the strain off hospitals. This approach may change the emphasis of hospital planning and its critical reliance on EPSS, offering alternatives that will produce improved outcomes.

For example, under the current preparedness paradigm, hospitals invest a significant portion of their mitigation budgets in EPSS. These systems are complex to operate and maintain, and vulnerable to single-point failures that can disable them. The use of such EPSS is predicated on the assumption that it is necessary to power critical areas of the hospital in an outage. Emergency planners could increase redundancy in this type of system by including portable generators that would be capable of providing limited power in critical areas if the EPSS fails. For example, portable generators could power mission-critical equipment in the ED, OR, and ICU areas of a hospital. This redundancy would increase the resilience of the hospital to power failures, help insure greater reliability, and could be made with modest facility improvements and staff training. Smaller, more numerous, back-up technology would also enable greater flexibility in adapting to the precise nature of each emergency. For example, if a facility suffers contamination due to power failure affecting negative-pressure rooms, mobile power sources could ensure that temporary facilities located adjacent to the hospital could be quickly set-up and powered, thus mitigating the impacts on emergency care for the surrounding community. Hospital emergency plans have already initiated a process of decentralized decision-making where onsite officials can initiate emergency response protocols. These efforts must continue decision-making to decentralize the nature of the technology used to provide emergency back-up to ensure maximum flexibility in future disasters.

Clearly, further reducing onsite vulnerability to power and water outages is difficult. Disaster planners at hospitals ought to begin planning for power and water outages by looking outside the walls of their facility to further reduce vulnerability. Already, each jurisdiction studied has begun this process. Taiwan has developed a real-time database to monitor hospital capacity (measured in terms of beds available) island wide.[212] If operational after a disaster, the system

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[212] S.T. Chang, Ibid.

would undoubtedly contribute to the resilience of the healthcare system by maximizing hospital capacity and relieving bottle-necks in the system. In Vancouver, health authorities have actively invested in onsite emergency communications capacity and regional coordination of disaster response. And finally, in California, disaster resource hospitals are tasked with the responsibility of coordinating and managing hospital capacity in the aftermath of disaster. However, all of these measures rely on two critical assumptions: 1. Emergency communications will be functional. 2. Hospitals will have adequate personnel onsite to adapt to and respond to the information communication systems provide.

The inability to communicate after a disaster has long been identified as a major barrier to effective response and recovery. Hospitals in all three areas have made investments in new technology that is hoped will overcome much of these difficulties but the ability to communicate in itself is not going to significantly reduce vulnerability or increase hospital capacity in an emergency. What has not been addressed is the ability to respond quickly to emerging conditions in a disaster. For example, in Vancouver, if St. Paul's hospital experiences an EPSS failure, hospital staff should have the ability to communicate the situation, and Vancouver Coastal Health Authority has responsibility for coordinating a response. On the provincial level and federal level, resources such as Emergency Hospitals are stored in regional centers and could be deployed at the request of the Vancouver Coastal Health Authority. However, even if the emergency hospital could be set-up in a timely fashion, there are no existing plans on how to staff the facility. Presumably, St. Paul's staff, and the staff of other regional hospitals, would be fully engaged in responding to the emergency at their hospital, thus staff would not be readily available. This could be address by establishing detailed personnel resource plans with hospitals outside the region. For example, medical staff in neighbouring health authorities could be pre-assigned to respond when an emergency is declared and report to duty at the emergency hospital site. This would assist in ensuring that not only would qualified personnel be available in the disaster area in short-order, they would also be properly equipped and tasked to respond effectively to the medical needs of the community. The need for this type of coordination was evident in the response to the Chi-chi earthquake where many foreign rescue teams had only limited effectiveness because of their lack of equipment (food and transportation in some cases) and their inability to coordinate with local rescue and recovery efforts. Thus, the ability to quickly install emergency medical treatment capacity and staff the hospital with qualified personnel from outside the disaster region and coordinate this with local health officials and hospitals would significantly mitigate the impact of prolonged power and water outages on hospitals.

The ability of decision-makers to recognize the significance and extent of the outage is critical in marshalling an effective response to the disaster. A brief comparison of decision-making at the highest levels in the Kobe earthquake and the Chi-chi earthquake illustrate this point. In Kobe, senior government officials in Tokyo did not feel the ground motion of the quake. As Japan experiences frequent earthquakes, it took several days for senior officials to fully grasp the urgency of the situation and marshal the full resources of the Japanese government to support the rescue and recover effort. On the other hand, the ground motion of the Chi-chi earthquake woke senior public officials, including President Lee, from their beds. While not aware of the specifics of the disaster, senior decision-makers were aware of its magnitude and within an hour of the quake held an emergency cabinet meeting to coordinate the response of the Taiwan government to the emergency.

Decision-makers and planners in Vancouver and Los Angeles need to be cognizant of this lesson, as these cities are located far from national centers of power, and in the case of Los Angeles, even State government offices in Sacramento. Decision-makers isolated from the disaster scene often rely on media reports to gain information in real time about the impact of the disaster. In New Orleans, one of the critical mistakes of the federal emergency response plan was partly caused by early media reports that indicated New Orleans had escaped catastrophic storm damage when in fact the failure of the city's flood defenses had failed. Decision-makers at the regional and site level must therefore plan and prepare to a standard that allows them to fulfill their critical functions without external assistance.

While a skeleton of this type of planning response exists in all three regions, greater planning and development of this alternative strategy is required. It is possible that decision-makers are somewhat reluctant to consider this alternative because the have not fully acknowledged the vulnerability to disaster in the current generation of hospital facilities. Another barrier is the significant cost of these alternatives, and the difficulty of rallying public support to make necessary financial investments in emergency facilities that the community hopes will never be required.

Question Two: How could these impacts be mitigated?

Strategies to mitigate the impacts of power and water outages on hospitals are discussed in Section 6.2 Recommendations.

Question Three: How could decision analysis tools help understand mitigation strategies?

Decision-analysis can play an increasingly important role in decision-making in emergency preparedness in hospitals. Several key factors have emerged from this study. Most critical is the observation that hospitals lack detailed information about the impact and frequency of power and water outages on their facility. In the absence of direct experience with dealing with disasters, decision-making about risk mitigation in hospitals accords strongly with the rule-following mode of decision-making. In this reality, one avenue to decrease vulnerability of hospitals to power and water outages is to create stringent standards and design effective mechanisms of compliance with these regulations. The trade-off of this approach is that many marginal facilities will elect to close rather than improve their facility to reach compliance, resulting in decreased access to quality healthcare, rather than improving healthcare.

Another lesson learned is that hospitals need to clearly identify and separate capital investment budgets for mitigation from operational budgets. It is also important that decision-makers broaden the context of which they examine the trade-offs of investing in increased mitigation at hospital facilities. Given the lack of systemic data about the prevalence of power and water outages affecting hospitals, decision-makers face great uncertainty about the financial justification of further investment in EPSS and back-up water supplies. However, even equipped with this financial information, the financial losses of occasional outages are unlikely to offset the financial investment necessary to reduce vulnerability. To overcome this, the scale of the decision must be considered carefully. If decisions about mitigation at hospitals are taken solely on the facility level, it is unlikely that hospitals will make the investments necessary to provide reliable emergency services when power and water infrastructure fail. This is because the ability to recoup these investments is only spread across patients who actually seek treatment that would not have been available without the investments in disaster resilience. Yet, all members of the community benefit when hospitals are more resilient. Thus, programs such as the Provincial Mitigation Program in British Columbia are a viable way of addressing hospital vulnerability at a regional level and providing funding to hospitals to invest in upgrading their resilience to ensure a functional post-disaster healthcare system. The failure of communities to invest in disaster preparation in hospitals is symptomatic of the broader weaknesses in disaster planning that have failed to prevent over US $608 billion dollars in losses during the 1990s alone.[213]

In order to avoid "policies without publics" it is important that future legislative efforts to reduce vulnerability frame the problem of disaster mitigation such that efforts to comply with that legislation will produce the desired outcome and to ensure that financial mechanisms exist to facilitate hospital's compliance. As SB 1953 has illustrated, unintended consequences of ill-framed decisions can lead to the reduction of healthcare, and scores of hospitals failing to reach

[213] Abramovitz, Janet "Unnatural Disasters" *World Watch Paper 158* Linda Starke (ed) Worldwatch Institute, 2001 p. 12

compliance, making rigourous enforcement of the regulations politically questionable. Had legislators included in their decision-making the financial constraints hospitals face, along with the substantial community benefits that arise from a resilient healthcare system, and hospital administrators could accurately detail the serious impacts of power and water outages on their facilities, it is possible that additional financial resources could be developed. Decision analysis can also assist in making the necessary, and difficult, trade-offs inherent in this policy question.

Decision-analysis can also play a significant role in post-disaster adaptation. It is critical that a facility identify restoration priorities in specific detail. For example, once an outage has occurred, hospital administrators need to decide whether or not to initiate the emergency plan. During a previous outage at NHMC, decision-makers elected not to initiate the HEICS plans which in retrospect they felt was a mistake. This failure was attributed to the fact that the primary decision-maker (an anesthesiologist) was engaged in duties relating to his primary responsibilities and did not have the time to understand the wider, cascading effects on hospital operations. The decision to initiate an emergency plan is difficult because it engages a set of procedures that directly impact patients and hospital staff, often at substantial financial cost to the institution. Decision-analysis can contribute to this decision by identifying key indicators ahead of time more specifically define conditions that require emergency procedures.

6.2 Recommendations

Organizational Resiliency

Disaster mitigation planning and legislative initiatives have both emphasized technical resiliency for coping with disasters. However, the literature review and interviews with hospital officials indicate that significant opportunities to mitigate the impacts of power and water outages exist. Efforts to increase organization resilience are often cost-effective and contribute toward building awareness of emergency protocols throughout all staff members of the hospital. A further benefit is that efforts to train and educate staff about emergency procedures bring emergency planners into direct contact with staff from all operational units of the hospital allowing planners to better understand the unique needs and vulnerabilities of each unit. The following include a list of steps that emergency planners can (and in some cases have taken) take to increase organization resiliency in their facility:

1. ***Implement an Integrated Emergency Plan*** Thorough orientation of all new staff members designed familiarize staff members with emergency plans and hazards faced by the facility.

2. ***Train and Develop Staff's Ability to Cope with Power and Water Outages*** Ongoing development of emergency response capacity through advanced training for key personnel in each department. Existing training emphasizes medical response to emergencies; training that addresses how to mitigate onsite impacts of disasters must be strengthened. Training should include information about coordination with city and regional disaster response officials, power and water utilities, and critical third-party support vendors such as EPSS maintenance.

3. ***Incorporate Emergency Protocols into Daily Operations*** It is the responsibility of emergency planners to develop emergency plans that can be effectively implemented by the entire organization. Therefore, it is essential that emergency protocols meet the operational requirements of the departments they serve. A good example of this type of planning is the use of "Bed Meetings" at Northridge Hospital Medical Center to determine hospital capacity in real-time during a recent power emergency.

4. ***Assist staff in responding to personal responsibilities during a disaster*** Hospitals have begun to take action on creating emergency staff protocols to activate staff for duty, assist in transportation and family support for staff during an emergency, and provide appropriate counseling and support for staff members working under difficult conditions. However, further steps are needed. Hospital administrators ought to work with physicians and their respective professional organizations to find ways to address physician staffing during emergencies. There is evidence from the Chi-chi earthquake that a significant portion of physicians able to report for duty during the emergency did not do so; physicians are not obligated by professional standards nor contractual obligations to report for emergency duty in most cases. Without adequate, trained health professionals onsite, efforts to reduce structural and non-structural vulnerability will not reduce community vulnerability. Hospitals, and emergency planning officials, need to address this by creating detailed plans to assist the key personnel in meeting their family obligations and ensuring the well-being of their loved-ones so that these individuals can contribute effectively to the emergency relief effort.

5. ***Support Staff throughout recovery process*** As frontline responders, hospital staff are dedicated to the serving their communities. During the first weeks after a disaster, staff are overwhelmed with the medical demands placed on them, compounded by difficult working conditions. As life begins to return to normal for many in the community, hospital staff frequently can only start to address their own recovery needs. The emotional stress of these efforts can be exacerbated by ongoing mental stress from the trauma experienced in treating victims of a disaster.

6. ***Develop Inter-Facility Cooperation Plans*** Hospitals need to develop more detailed plans for inter-facility cooperation. Taiwan has begun this process with its internet-based hospital capacity analysis software. Vancouver has taken steps with coordination of emergency healthcare taking place at regional levels through Health Authorities. Los Angeles has created a similar system with "Disaster Resource Hospitals." While positive starts, these arrangements lack detail and development in how they will be utilized in an actual power or water emergency, and share potentially catastrophic vulnerability to communication and transportation interruptions. It is essential that hospital planners take steps to access community emergency communication resources such as distributed amateur radio networks that may prove to be the only reliable communication technology in the immediate aftermath of a major disaster. These plans should be developed to the point where individual staff members at one institution know what their responsibility would be during an emergency at the partner facility.

7. ***Develop Regional Cooperation and Evacuation Plans*** Vulnerability to power and water outages remains significant; even with massively increased investment in technical resiliency most hospitals will remain highly vulnerable to power and water disruptions for the foreseeable future. Several options to increase organization resilience exist, but will require extensive planning and coordination to implement. The first option is to identify key staff working at hospitals outside of a hospital's region. Ideally, the staff should be located nearby, but far enough to be isolated from the disaster area. In the case of widespread power failures such as the Northeast Blackout, this may prove impossible, but in geographically constrained emergencies such as severe storms or earthquakes, it is probable that hospitals in neighbouring regions will remain largely unaffected operationally. By identifying staff in advance, and securing

functional transportation such as helicopter, staff from these regions could be brought in to support the affected hospital within twelve hours. This would provide relief for staff, and mitigate potential staffing shortages caused by staff being unable to report for duty to the disaster. A more complicated alternative would be to identify extra-regional hospitals that could intake evacuated patients from the affected hospital.

Technical Resiliency

1. ***Enforce existing regulations*** Building design standards that include non-structural mitigation standards such as SB 1953 in California and the Canadian Standards Association (1995 under revision expected 2005) are "probably adequate" in mitigating the seismic threat to hospitals, however, even today, new hospitals are not built to code.[214]

2. ***Improve EPSS Testing Protocols*** While all hospitals included in this study have strengthened testing and maintenance protocols for EPSS equipment, none of them test the system's ability to sustain power supply under longer-term operating conditions. Given the evidence from Taiwan, it is essential for EPSS systems to remain operable for at least seven days.

3. ***Increase Capacity of EPSS systems*** All EPSS systems in the hospital have the capacity to supply power for mission critical facilities such as the ED, ICU . OR and . Beyond these medically essential areas, there is more variance in the extent of the EPSS coverage. Emergency planners ought to consider how an extended power outage would affect their overall ability to operate. From this perspective, emergency power for facilities such as elevators, food service and laundry departments, administrative

[214] Jay Lewis

offices become critical in terms of maintaining the operational capacity of the hospital in an extended outage. In particular, it is worth noting, that in hospitals that have experienced serious outages (e.g. Puli Christian Hospital) substantially increased their EPSS capacity in the wake of the outage.

4. ***Assess Reliability of Third-Party Vendors*** A great deal of uncertainty in emergency preparedness exists because of doubts about the ability of third-party vendors to honour contract obligations in an emergency. At present, hospitals have not addressed this uncertainty in their planning and it remains a critical vulnerability. Simply having a contract in place to provide fuel or water in an emergency does not reduce vulnerability to the hazard if vendors are unlikely to be able to honour the contract. Changes in hospital operations such as contracting maintenance tasks to third-party vendors has greatly increased the operational efficiency of hospitals. It also has the potential to increase vulnerability to disasters. Hospitals need to take steps to ensure that third-part vendors are qualified to offer critical services and must also assess the likelihood that each vendor will be able to provide services during an emergency. One example of how this has not been done to date is that Vancouver area hospitals depend on medical oxygen shipments from Alberta.

Adopting sustainable disaster mitigation plans for hospitals requires not only adopting these recommendations, but also a more fundamental change in how the problem of emergency preparedness is framed. In all locations studied, emergency planning was highly contingent on ad hoc funding. This means that instead of strategic plans that holistically work to reduce vulnerability, hospitals invest in equipment. However, without an effective emergency plan, even the best communication system will not operate. More importantly, because of the lack of strategic planning, many emergency plans are unlikely to function in a true emergency. Consider examples such as demand management systems that are dependent on the internet for their operation or transportation networks for the just in time delivery of mission critical supplies. Clearly, emergency planning and vulnerability reduction planning must look beyond emergency scenarios to consider how vulnerability reduction can be incorporated into typical hospital operations.

The above recommendations represent a starting point for both practical and strategic action; practical in that many of the recommendations are derived from hospitals and emergency planners who have experienced power and water outages and learned valuable lessons from these experiences, strategic in that these recommendations better integrate emergency planning within hospitals and their surrounding communities. One of the strongest themes that emerged in all of the case studies was the need for hospitals to reach out to other emergency planning officials and the local community. To generate the necessary support and funding to achieve many of these goals, it is essential to engage in dialogue with a broader set of community stakeholders, define and characterize the risks to each facility, and work as a community to assist hospitals in reducing vulnerability to power and water outages.

Further research is needed in several areas of disaster mitigation in hospitals. First, it is essential that improve their organization's ability to learn from the experiences of other hospitals. It is worth noting that Puli Christian Hospital sent several medical and planning officials to investigate the aftermath of the Southeast Asian Tsunami on hospitals in that region in order to better develop their own emergency response. Second, the vulnerability and reliability of EPSS systems and other critical infrastructure need to be better understood from an engineering perspective. Hospitals are increasingly complex and reliant on reliable power systems, yet frequently depend on old equipment for back-up operations. There is no clear sense of how reliable these equipment are in an emergency, nor realistic testing protocols to identify potential shortcomings before the onset of disaster. This type of research may lead to broader changes in EPSS systems and emergency water supplies that will further reduce vulnerability. Last, emergency planning would benefit greatly from a rigourous application of decision analysis tools to characterize existing vulnerability, and rank decision alternatives according to community preferences.

Current efforts to reduce vulnerability to power and water outages at hospitals have made progress but much remains to be done. It is essential that critical infrastructure such as hospitals become part of a community's broader plans to reduce vulnerability to natural and human-induced disasters if planners are to realize the promise of disaster resilient communities.

References

Adams, John and Stephen Halchuk, "Knowledge of in-slab earthquakes needed to improve seismic hazard estimates for southwestern British Columbia" Geological Survey of Canada, 2001 Available online at: http://www.seismo.nrcan.gc.ca/hazards/inslab2000/index.php

American Hospital Association, "Hospitals Appear to be Coping with Power Outage" August 15, 2003 Available online at: http://www.hospitalconnect.com/ahanews/jsp/display.jsp?dcrpath=AHA/NewsStory_Article/data/ann_030815_Outage&domain=AHANEWS

Amir Dan Rubin, Guy L. Clifton: Survey Reveals Need To Strengthen Financial Viability Of State Trauma System: Texas Trauma System Viability. *The Internet Journal of Healthcare Administration.* 2002. Volume 1 Number 2.

Auf der Heide, Erik "Disaster Response: Principles of Preparation and Coordination" 1989, http://orgmail2.coe-dmha.org/dr/Static.htm Chapter Two

Ariu, Toshio "Impact of North America Blackout" Central Research Institute of Electric Power Industry, 2004. Available online at: http://criepi.denken.or.jp/en/e_publication/pdf/den398.pdf

Bazerman, Max Judgment in Managerial Decision-making Fourth Edition, Wiley 1998.

Birkland, Thomas A. After Disaster: Agenda Setting, Public Policy and Focusing Events Georgetown University Press, Washington, D.C. 1997

Bruneau, M., Chang, S.E., Eguchi, R.T., Lee, G.C., O'Rourke, T.D. Reinhorn, A.M., Shinozuka, M., Tierney, K., Wallace,W.A. and von Winterfeldt, D. A Frameworkd to Quantitatively Assess and Enhance the Seismic Reslilence of Communities, Earthquake Spectra, 2003

Burby, Raymond J. "Natural Hazards and Land Use: An Introduction" in *Cooperating with Nature: Confronting Natural Hazards with Land Use Planning for Sustainable Communities* 1998 Washington, D.C.: Joseph Henry Press

Canadian Council on Health Services Accreditation 2004. http://www.cchsa.ca/

Canadian Forces, "Canadian Forces Disaster Assistance Team" 2005, Available online at: http://www.forces.gc.ca/site/Newsroom/view_news_e.asp?id=301

Catholic Healthcare West, "About Us" Available online at: http://www.chwhealth.org/stellent/websites/get_page_cache.asp?nodeId=5005410

CBC News, "Blackout by the Numbers" 2003 http://www.cbc.ca/news/background/poweroutage/numbers.html

Chang, Lung-Sheng "The Role of Government and Civilian Assistance in Providing Urgently Needed Social Services and Redevelopment Work in Emergency Situations: The Case of the Recent Earthquake in Taiwan" Council for Economic Planning and Development, Executive Yuan, R.O.C. p. 267 Available online at: http://www.asria.org/farchive1/1104481960/1105353309/Taiwan_921_earthquake.pdf

Chen, Kow-Tong, Wei Chen, Josephine Malilay and Sing-Jer Twu "The Public Health Response to the Chi-Chi Earthquake in Taiwan, 1999" in *Public Health Reports* November-December 2003, Volume 118

Chisholm, Dan "Energy Crisis? Summer Blackout Demonstrates the Importance of Generator Maintenance" in *Health Facilities Management* October 2003, 28-34 p. 30

Chang-Gung Memorial Hospital website, Available online at : http://www.cgmh.org.tw/eng2002/about01.htm#03

Chou, Frank Huang-Chih, Tom Tung-Ping Su, Wen-Chen Ou Yang, Ming-kun Lu, and I-Chia Chien "Survey of Psychiatric Disorders in a Taiwanese Village Population Six Months After a Major Earthquake" in Journal of Formosa Medical Annex, Volume 104, No. 5 2000

Clague, John "The Earthquake Threat in Southwestern British Columbia" Available online at: http://epe.lac-bac.gc.ca/100/200/301/ocipep-bpiepc/earthquake-e/clague.pdf

CogNexus Institute "Wicked Problems" 2005, http://www.cognexus.org/id42.htm

Committee on the Science of Earthquakes Living on an Active Earth National Academy of Sciences Washington, D.C. 2003

Committee on Seismology and Geodynamics, National Research Council, "Improved Seismic Monitoring – Improved Decision-Making: Assessing the Value of Reduced Uncertainty" 2005

Dear, Michael "In the City, Time Becomes Visible: Internationality and Urbanism in Los Angeles, 1781-1991" in The City: Los Angeles and Urban

Theory at the End of the Twentieth Century Allen J. Scott and Edward W. Soja (eds.) University of California Press, 1998

Department of Justice Canada "Constitution Acts: 1867 to 1982" 2004 http://laws/justice.gc.ca/en/const/c1867_e_html#distribution

Drabek, T. E. Human system responses to disaster: an inventory of sociological findings, New York, 1986, Springer-Verlag

Drake, Denny "Disaster Preparedness" in *Risk Management Handbook for Health Care Organizations* Robert Carrol (editor), Second Edition, American Society for Healthcare Risk Management, 1997

Earth Consultants International "Technical Background Report to the Safety Element of the General Plan, City of Glendale" 2003 Available online at: http://www.glendaleca.com/government/planning/safety_element/TBR_Cover--Introduction_Table_of_Contents.pdf

Earthquake Engineering Research Institute, "Earthquake Spectra" Supplement C to Volume 11 of *The Professional Journal of the Earthquake Engineering Research Institute* April 1995

EM-DAT: The OFDA/CRED International Disaster Database Université Catholique de Louvain - Brussels - Belgium http://www.em-dat.net/figures_2004.htm

Emerson Power Network "St. Joseph's Hospital Case Study" Emerson Power, http://www.gotoemerson.com/brands/net_power/cs0.html

Engyndenyz, . ; M. Bulut, MD; H. Özgüç, MD; R. Tokyay, MD "The 24 Hour, Post-Earthquake Experience of a University Hospital in Turkey" in Prehospital Disaster Medicine 2000, 15(3):s76 Available online at: http://pdm.medicine.wisc.edu/Engyndenyza.htm

Environment Canada, 2002 "The Worst Ice Storm in Canadian history?" [July 4, 2004] http://www.msc-smc.ec.gc.ca/media/icestorm98/icestorm98_the_worst_e.cfm

Environmental Literacy Council "Electric Power Grids and Blackouts" 2005 Available online at: http://www.enviroliteracy.org/article.php/1277.html

Essinger, Kaj and Bengt Linder "Disaster Medicine in Europe: Organisation and Trends " http://www.hope.be/07publi/leaflet/disaster/frame.htm

EQE Consulting "Chichi, Taiwan Earthquake of September 21, 1999 (M7.6) Available online at:

http://www.absconsulting.com/resources/Catastrophe_Reports/Chichi-Taiwan-1999.pdf

Felch, Jason "Valley's Oldest Hospital to Close: Shuttering of Van Nuys facility will add to the sharply rising toll of ER shutdowns in county." in the Los Angeles Times, August 20, 2004.

Fischhoff, Baruch et al "Defining Risk" in Readings in Risk Theodore Glickman and Michael Gough (eds.) Resources for the Future, Washington, D.C., 1990.

Globe and Mail "Most Canadian ER visits not emergencies" in *The Globe and Mail* September 14, 2005 Available online (archived) at: http://www.theglobeandmail.com

Government Information Office, "Taiwan Yearbook 2004" 2004 Available online at: http://www.gio.gov.tw/taiwan-website/5-gp/yearbook/P243.htm#1

Greenwald, Peter W., Anne F. Rutherford, Robert A. Green, MD and James Giglio, MD "Emergency Department Visits for Home Medical Device Failure during the 2003 North America Blackout" in *Academic Emergency Medicine* Volume 11, Number 7

Halliday, R.A. "Water, Critical Infrastructure Protection and Emergency Management" Public Safety and Emergency Preparedness Canada, 2003 http://www.ocipep.gc.ca/research/resactivities/CI/2002-D016_e.asp

Hanna, James Disaster Planning for Health Care Facilities The Canadian Hospital Association, Third Edition, 1995

Haefke, Clifford "Combined Heat & Power (CHP) for Minnesota Healthcare Facilities" Presentation to Healthcare Environmental Awareness & Resource Recovery Teamn (HEARRT) Thursday, January 8th, 2004 Available online at: http://www.chpcentermw.org/pdfs/040108_chp_hearrt_haefke_StPaul_MN.pdf

Health Canada, "Canada Health Act Overview" 2005, http://www.hc-sc.gc.ca/medicare/chaover.htm

Health Canada, "Emergency Preparedness" http://www.hc-sc.gc.ca/english/epr

Homer-Dixon, Thomas The Ingenuity Gap: Can We Solve the Problems of our Future? Vintage Canada, Toronto. 2001

Holmes, William "Program for Seismic Rehabilitation of Existing Hospitals in California" presented at Pan Pacific Hazards 96, Vancouver, 1996. Available

online at:
http://www.ruthchek.com/flash/frame2/who/resume/WTHSB1953link.pdf

Hounsell, Dan “Fallout” in *Maintenance Solutions* October 2003, Trade Press Publishing http://www.facilitiesnet.com/ms/article.asp?id=1947

Hsu, Edbert, Matthew Ma, Fang Yue Lin, Michael J. VanRooyen and Frederick M. Burkle Jr. “Emergency Medical Assistancce Team Response following Taiwan Chi-chi Earthquake” in *Prehospital and Disaster Medicine* January-March 2002 http://pdm.medicine.wisc.edu

Japan-Hong Kong Joint Reconnaisance Team “Taiwan Jiji Earthquake September 30 to October 5, 1999

Joint Commission on Accreditation of Healthcare Organizations, “Standing Together: An Emergency Planning Guide for America’s Communities” JCAHO, 2005 Available online at:
http://www.jcaho.org/news+room/press+kits/ems/essesntial_comp_plan_process.htm

Jones, Wanda J “Renewal by Earthquake: Designing 21st Century Hospitals in Response to California’s Seismic Safety Legislation” California HealthCare Foundation, March 2004.

Kahneman, Daniel and Amos Tversky “Prospect Theory: An analysis of decisions under risk” *Econometrica,* 47:313327, 1979

Keeney, Ralph “Framing Public Policy Decisions” in *International Journal of Technology Policy and Management”* 2004 Vol. 4, No. 2 p. 95-115

Keeney, Ralph “Decision Analysis: An Overview” in Operations Research, Vol. 30, No. 5, September-October 1982

Kile, James C., Stephen Skowronski, Mark D. Miller, Stephan G. Reissman,, Victor Balaban, Richard W. Klomp, Dori B. Reissman, Hugh M. Mainzer, Andrew L. Dannenberg “Impact of 2003 Power Outages on Health and Emergency Response” in *Pre-hospital and Disaster Medicine* March-April 2005 http://pdm.medicine.wisc.edu

La Corte, Rachel “France’s stirred up Florida’s Environment” AP Press, September 7, 2004 [Accessed September 8, 2004] Available online at: http://www.msnbc.msn.com/id/5930983/

Levy, Clifford, Kate Zernike “The Blackout: Hospitals: Lessons Learned on 9/11 Help Hospitals Respond” in the New York Times, August 16, 2003 (Archived) Available online at:

http://select.nytimes.com/gst/abstract.html?res=F60D15FD3E540C758DDDA10894DB404482

Lezon, Dale "Power Failure forces hospitals to scramble" The Houston Chronicle, June 11, 2001 http://www.chron.com/cs/CDA/ssistory.mpl/front/93724

Lin, Cheng-Horing "A Major Earthquake in the Strong Crust: The 1999 Chi-chi Earthquake" in *Western Pacific Earth Sciences Vol. 1 No. 3* August, 2001

Lovern, Ed "How much is enough?" Modern Healthcare, Chicago: Nov. 19, 2001, Vol.31, Issue. 47

MacQueen, Ken "When B.C. gets hit" in *Maclean's Magazine* May 16, 2005 Available online at: http://www.macleans.ca/topstories/canada/article.jsp?content=20050516_105684_105684

Madigan, Nick "Los Angeles Emergency Care Crisis Deepens" *New York Times,* August 21, 2004 http://www.cepr.net/Economic_Reporting_Review/nytimesarticles/la_emergency_care.htm

Malnic, Eric and Patrick McGreevy "Power Outage: Here We Go Again" in Los Angeles Times, October 12, 2005 Available online at: http://www.latimes.com/news/local/la-me-outage12oct12,1,1195753.story

March, J. and J. Olsen *Ambiguity and Choice in Organizations* Universitetsforlaget, Bergen, Norway 1976

March, James G. *A Primer on Decision-making: How Decisions Happen* The Free Press, Toronto, 1994

Meserve, Jean, John Zarrella and David Mattingly "Katrina Gone but Impact Continues" August 30, 2005 Available online at: http://www.cnn.com/2005/WEATHER/08/30/katrina.impact/

Mileti, Dennis 1999 Disaster by Design Washington, D.C.: Joseph Henry Press

Ministry of Interior "□ □ □ □ □ □ □ □ □ □ □ □ □ □ □ " (Taiwan Disaster Report) 2002 (in Chinese) http://www.moi.gov.tw/stat/topic/topic148.htm

Mitchell, James K. "What's in a name?" Issues of Terminology and Language in Hazards Research" in *Environmental Hazards* 2 (2001)

Moody's Investor Services, "Rating Update: Catholic Healthcare West" August 12, 2005 Available online at: http://www.chwhealth.org/stellent/groups/public/@xinternet_con_sys/documents/webcontent/096895.pdf

Northwest Renal Network, "Monitoring Your Dialysis Water Treatment System" June, 2005. p. 16 Available online at: http://www.nwrenalnetwork.org/watermanual.pdf

Office for Statewide Health Planning and Development "Retrofit Program – SB1953" http://www.oshpd.ca.gov/FDD/SB1953/index.htm

Office of Statewide Health Planning and Development "Summary of Hospital Seismic Performance Ratings April 2001" 2001 Available online at: http://www.oshpd.ca.gov/SB1953/sb1953rating.pdf

Nantou County Government, "Introduction to Nantou" http://www.nantou.gov.tw/english/main.htm

National Weather Services Forecast Office "Tropical Storm Allison Floods June 5-9 2001" National Weather Service http://www.srh.noaa.gov/hgx/projects/allison01.htm

Parks Canada "Time for Nature" 2004 [Accessed July 14, 2004] Available online at: http://www.pc.gc.ca/canada/nature/archives/2003/dec/index_E.asp

Patton, Carl and David Sawicki, Basic Methods of Policy Analysis and Planning Second Edition, Prentice Hall, New Jersey, 1993

Petak, William J. "EERI 2003 Distinguished Lecture: Earthquake Mitigation Implementation: A Sociotechnical System Approach" 2003, www.nd.edu/~eeriund/Speakers/Petak%20abstract.pdf

Petak, William J. and Daniel J. Alesch "Organization Decision-making with Respect to Extreme Events: Healthcare Organizations Respond to California's SB 1953" http://www.mceer.buffalo.edu/publications/resaccom/0304/09_alesch.pdf

Public Safety and Emergency Preparedness Canada http://www.ocipep.gc.ca/ndms/index_e.asp

Rachman, Tom "Power failure strikes nearly all of Italy; Finger-pointing crosses border" Record, North New Jersey, September 29, 2003. http://powermarketers.netcontentinc.net/newsreader.asp?ppa=8knpq%5FZfjqrnpw%5BUok%27%40%3E%20bfeiZ%21

Rodrigue, Christine et al. “Construction of the "Northridge" Earthquake in Los Angeles' English and Spanish Print Media: Damage, Attention, and Skewed Recovery” 1997 http://www.csulb.edu/~rodrigue/scehc97.html

Schneider, Andy and David Rousseau “Address the Health Care Impact of Hurricane Katrina” (Report #7387) Kaiser Commission on Medicaid and the Uninsured. Available online at: http://www.kff.org/uninsured/upload/7387-2.pdf

“Scientists Work to Predict Earthquakes” [Donald Turcotte and William Baulkin] Talk to the Nation (Ira Flatow, Interviewer) Broadcast October 14, 2005, Story # 4958959 Available online at: www.npr.org

Scott, Allen J., John Agnew, Edward W. Soja and Michael Storper. 2002. “Global City_Regions.” In *Global City_Regions* by A.J. Scott, Ed. Oxford, UK: Oxford University Press.

Sheaffer, John R. et al *Flood Hazard Mitigation Through Safe Land Use Practices.* 1976 Chicago: Keifer and Associates

Seligson, Hope, Shoaf, Kimberley and Shinozuka, Masanobu “Multi-Hazard Modeling of Medical System Performance” ABS Consulting

Siemens Power Transmission and Distribution “Analyzing the Northeast Blackout 2003” 2005 http://www.pti-us.com/pti/2003blackout/blackout.cfm#recentevents

Southern California Earthquake Data Center, “Northridge Earthquake” http://www.data.scec.org/chrono_index/northreq.html

Statistics Canada “2001 Community Profiles” 2001 Available online at: http://www12.statcan.ca/english/profil01/Details/details1pop.cfm?SEARCH=BEGINS&PSGC=59&SGC=5915022&A=&LANG=E&Province=59&PlaceName=Vancouver&CSDNAME=Vancouver&CMA=&SEARCH=BEGINS&DataType=1&TypeNameE=City%20%2D%20Cit%E9&ID=1259

Stehr, S.D. "In Harm's Way: Disasters, Public Policy, and the Urban Landscape” in *Urban Affairs Review*, November 1999, vol. 35, no. 2, pp. 301-303(3) SAGE Publications

Taipower “The Fifth Distribution Projects” 2003, Available online at: http://www.taipower.com.tw/~d105/eng/Fifth_Distribution.htm

Tierney, Kathleen Environmental Hazards Washington, D.C. Joseph Henry Press, 2001

Trujillo, Melissa "Florida ER's Swamped in Wilma's Aftermath" Associated Press, October 30, 2005 Available online at: http://sfgate.com/cgi-bin/article.cgi?f=/n/a/2005/10/30/national/a144651S88.DTL&type=health

Tsu, T. Soong, Yao, George C. and C.C. Lin "Damage to Critical Facilities Following the 921 Chi-Chi, Taiwan Earthquake" 2001 Available online at: http://mceer.buffalo.edu/publications/resaccom/00-SP01/Chapter3.pdf

T. Soong, George C. Yao and C. C. Lin MCEER, 2000 Available online at: http://mceer.buffalo.edu/publications/resaccom/00-SP01/Chapter3.pdf

UNAIDS "Global Summary of the HIV/AIDS epidemic 2004" http://www.unaids.org/wad2004/EPIupdate2004_html_en/Epi04_02_en.htm#P16_3133

UN Habitat, http://www.unhabitat.org/habrdd/statannexes.htm

Warner, Margaret "Power Outage" August 14, 2003 Available online at: http://www.pbs.org/newshour/bb/fedagencies/july-dec03/blackouts_08-14.html

Williams, Scott "Houston Staff Slosh, dive into evac mode" NurseWeek, http://www.nurseweek.com/news/features/01-06/flood.html

Wilson, Edward O. Consilience Random House, New York 1999