POLITECNICO DI MILANO

Business Continuity Management Framework for Hospitals Based on System Dynamics Analysis

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ABSTRACT

Hospital facilities are critical infrastructures for disaster response that required 24-hours continuous operation to fully respond to community needs. However, it is demonstrated that the capacity of many general hospitals during unpredicted disasters has been compromised to the structural damage of building facilities and interference of non-structural functions itself. Hence the aim is to enhance hospital disaster preparedness and facility adaptation to deal with these heightened incidences. The purpose of this thesis is to develop a business management framework for hospitals to maintain functionality in the aftermath of a major disaster.

To achieve this aim, research were conducted within constructionist ontology and interpretivist epistemology, underpinned by quantitative methods capturing multiple realities embedded in hospital stakeholders' experiences. The research adopts a system dynamics model to form causal interdependencies between hospital functional continuity factors in three dimensions. These factors are mainly derived from hospital safety assessment guide by World Health Organization so to define business continuity conditions in a complex hospital system. System dynamics using Vensim PLE software is applied to a Shanghai hospital case study to evaluate and verify its functional continuity subsystem performance by giving functional continuity factors simulation functions. Through simulation results, critical factors which affect hospital continuous operational level are identified. Based on this, business continuity framework is proposed; pre-event risk mitigation to reduce the effects of the disaster on facility, during-event emergency response plan to organize efficient evacuation and backup resource, and post-event recovery service to completely recover all the facility functions.

Key words: business continuity management (gestione della continuità operative); hospital functional continuity (ospedale continuità funzionale); system dynamics (dinamica dei sistemi)

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CHAPTER 1: INTRODUCTION

The aim of this chapter is to show why retaining business continuity of hospitals is essential for responding to the increasing incidence of disasters or unpredicted events. After highlighting the significance of enhancing organizational resilience, the chapter illustrates the scope of this thesis including objectives, methodologies and general outline.

1.1 Background to research problem

Each natural or manmade hazard has different physical characteristics that create risks to life safety and property, consequently requires different methods of risk management. Especially, the number of schools and hospitals being destroyed or damaged during disasters was unacceptably high, and in disaster-prone areas like Latin America and the Caribbean, more than half of the 16,000 hospitals are at high risk for disasters. Flooding events in 2011 caused significant damage to infrastructure, hospitals, loss of life and even devastating public health issues, particularly in Europe and Asia, including China and Pakistan. During these events, hospitals were severely impacted because of both physical damages and inability to obtain resources to deliver care services or sustain lives, such as fuel for generators[1]. The Nepal Earthquake in April 2015, killed more than 8000 people and destroyed more than 400 hospitals, causing rescue teams and hospitals struggle to cope with the wounded[2]. Disaster damage to health systems is a human tragedy, results in huge economic losses, deals devastating blows to development goals, and shakes social confidence. Making hospitals and health facilities safe from disasters is an economic requirement, and also a social, moral and ethical necessity.

Hospitals, designated as a form of Critical Infrastructure in many countries, are demanded to maintain constant operation. In many disaster instances, deaths of hospital occupants were the direct results of collapsing physical infrastructures. In the wake of a disaster, an affected population not only converges at hospitals solely to seek healthcare services, but also the stricken general public regards hospitals as centralized points of community support and assistance which they gather at for air conditioning, electricity, food, water, and accurate information. Furthermore, since hospitals operate 24 hours per day and seven days per week, it is also perceived as a hub for emergency personnel, relatives searching for missing ones in hope of locating lost family members. Hence, the continued function of hospitals provide reassurance that the society have not broken down by disasters, and allows community assistance to be coordinated through recognized points of support of which hospitals play an essential role.

Special attention must be given to ensuring the physical and functional integrity of hospitals and health facilities in emergency conditions. The United Nations International Strategy for Disaster Reduction (UNISD) in collaboration with the World Health Organization (WHO), United Nations Educational Scientific and Cultural Organization (UNESCO), United Nations International Children's Emergency Fund (UNICEF), World Bank, Asian Development Bank (ADB) and other partners aim to raise public awareness and create a demand for safe schools, hospitals and health facilities[3]. The objective is to form a core part of the Making Cities Resilient campaign, the urgent need to disaster-proof public services and infrastructure such as schools and hospitals is evident when earthquakes, typhoons and cyclones destroy thousands of these essential facilities globally. In recognition of this need for collaborative efforts to mitigate damages and loss of function, international public health, humanitarian and relief organizations such as Pan-American Health Organization (WHO/PAHO), UNISD, World Bank, the Joint Commission International (JCI) and the World Association for Disaster and Emergency Medicine (WADEM) have sponsored a series of global forums intent on developing guidelines for designing, constructing, and evaluating safe and resilient hospitals[4]. Seizing the chance, they also promoted the "Safe Hospital" model as an integral component of disaster reduction risk planning in the healthcare sector. "Safe Hospital" are those hospitals built with a level of resilience that strengthens their capacity to remain functional in disaster situations. Safe hospitals and other health facilities must remain operational in the aftermath of emergencies and disaster. Action to make hospitals and other health facilities safe and operational before, during and after disasters through the implementation of the Safe Hospitals Initiative must remain a priority for disaster risk reduction. Although nations vary widely in their approach and responses to disasters, common organizational models and benchmarks have been proposed in the context of establishing institutional measures and mechanisms for building new and retrofitting existing hospitals to meet minimum standards of safe and resilient hospitals. This includes terms of infrastructure and capacity to sustain facility-oriented and community-integrated disaster response.

Business continuity management (BCM) aims to avoid or mitigate risk to reduce the impact of a disaster or unpredicted event. While BCM is an emerging practice, there is limited evidence within the disaster preparedness of hospitals. If facility management is integrated with other aspects of disaster recovery and business continuity, disasters may be more easily resolved. Facility management (FM) is usually involved in most disaster situations that affect a building or the location of the building. According to the International Facilities Management Association (IFMA), facility management is a discipline that encompasses multiple subjects to ensure functionality of the built environment by integrating people, place, process and technology. In other words, facility management goes beyond just a building and its operational infrastructure. It addresses all aspects of a building, the land on which it is situated, and even the external surroundings, such as above-ground and below-ground infrastructures, such as utilities and transportation. Whilst there are not clear BCM applications to organizations such as hospitals, it is confirmed that there is a strong linkage between disciplines integration of BCM and FM and the capability of hospitals to sustain operations and the continuous delivery of care. This thesis has undertaken the tasks of identifying a number of approaches and strategies that enable business continuity in hospitals.

1.2 Aim and scope of the research

1.2.1 Research contents and significance

Research contents

Although hospitals vary greatly in terms of their size, department organization and market demand, their major functions and facility arrangements remain broadly the same. Therefore a standardized approach to ensuring their continued operation can be prospected as guidelines for safe hospital management. The notion of enhancing capability to sustain continuous service operations is critical when considering the wide range of possible disaster risks that hospitals face.

The purpose of this research is to identify key resilience factors, their interdependencies, and develop a Business Continuity Management Framework for hospitals. This involves ①establishing safe hospital functional continuity factors by three dimensions including structural, functional and organizational components, ②applying system dynamics model to a practical case study-Shanghai general hospital to evaluate interdependencies of each factor in order to find key functional elements. ③incorporating critical functional continuity factors into a sequential business continuity framework.

Significance

Safeguarding organizations from multitude of threats has long been the focus for risk management and disaster management researchers and practitioners alike, especially within a hospital facility context. The increasing complexity of natural, social and built environment threats and growing sophistication of interlinked and interdependent operating procedures have given rise for new approaches to protecting hospitals from unexpected events. Traditional methods such as risk evaluation and disaster recovery plan has proven limited effects to offer a comprehensive strategies that integrate structural, functional and organizational components. Therefore, the traditionally narrow focus on reactive approaches has reinforced the need for more practical and holistic approaches of organizational protection and preparation in hospitals.

In terms of practical relevance and theoretical contribution, the BCM approach proposed by this thesis contributes to a safer built environment, towards more resilient communities. The research comprehensively integrates theories of facility management, risk management, disaster management and business continuity management, which enriched the theoretical background of the study and the joint exploitation of these related disciplines.

The system dynamics model for risk and resilience analysis provides a scientific and objective basis for determining the critical factors of service continuity, which enhances the accuracy and efficacy of the approach to be put in use.

More practically, the BCM framework proposed in this research could be used by government officials, policy makers, and healthcare chief operations managers for promoting the practical implementation of hospital disaster resilience.

1.2.2 Propositions and methodologies

Assumptions

Since the aim is to establish measures and mechanisms for facilitating hospitals to enhance disaster resilience in terms of care delivery and facility-oriented functional operating procedures, facility management criteria will serves as the basic research setting for this investigation, which encompass structural, functional and organizational elements as hospital resilience dimensions.

The thesis assumes that the hospital safety index elaborated by the World Health Organization (WHO) reflects the three aspects of facility management in which all the hospital resilience factors are comprised. The thesis assumes a case study of Shanghai municipal public health center (No.2901, Caolang Road, Jinshan District, Shanghai) represents China's general hospital facilities and disaster management, so that universal business continuity framework would apply to general hospitals based on the research results of a single case study.

There are several BCM models available, the research adopts the standardized phased model reported in the China National Emergency Management Guide[5] including pre-event preparedness, during-event response and post-event recovery. Preparedness involves practice and training of the continuity, plan which comes from risk management and various scenario simulations. Recovery efforts cover restoration of all the activities to the normal level. These three stages demonstrate comprehensive business continuity management and procedures.

Methodologies

Considering the way to achieve the research objectives, the following methodologies are adopted:

①Main data collection methods are observations and semi-structured interviews which were taken at hospital management level. However, this constructivist and interpretivist data collection paradigm has limitations. To guarantee the credibility of data, a first visit to the hospital allowed the researcher to familiarize with and get an independent insight of the hospital environment, also a summary of first interview conversations is verified by participants and then revise their viewpoints.

②System Dynamics (SD) is applied to quantitatively evaluate the influence of critical functional continuity factors and their interdependencies. The quantitative description of interdependencies among these factors to be analyzed in system dynamics model are formed and induced by expert's assumptions and perceptions.

③A single confirmatory case study in two kinds of scenarios was finally conducted in a real hospital environment to test and validate the set of critical resilience factors and functions as well as the SD model.

1.2.3 Thesis outline

Chapter 2 reviews the literatures on disaster preparedness and resilience in hospitals. The related basic theories and approaches - consisting of facility management, disaster management, and business continuity management - are illustrated and critically discussed. This sets the stage to review hospital disaster resilience and research achievements based on these theories, including facility management model, vulnerability assessment and mitigation strategies, disaster preparedness plans and business continuity strategies.

Chapter 3 introduces the key resilience factors for hospitals, which come from the hospital safety index developed by WHO, covering structural, functional and organizational aspects. These resilience factors are described within the facility management context.

Chapter 4 assesses the interdependencies of resilience factors to identify critical hospital disaster resilience indicators within a System Dynamics model. The overall hospital continuity system is composed by three subsystems, which are: the functional support subsystem, the medical function subsystem, and the continuity safeguarding subsystem. Resilience factors are associated to each subsystem according to their categories and interdependencies. These factors are determined as variables, parameters with values and functions given by participants from semi-structured interviews. By two kinds of scenario simulation, the results are compared and critical factors are found. Finally, three approaches are applied for model testing and validation and BCM framework and strategies are proposed for hospital along three stages: pre-event preparedness, during-event response and post-event recovery.

Chapter 5 discussed the value and feasibility of the thesis.

Chapter 6 draws the conclusions thesis and suggests some directions for future research.

The thesis research outline is presented in Figure 1.

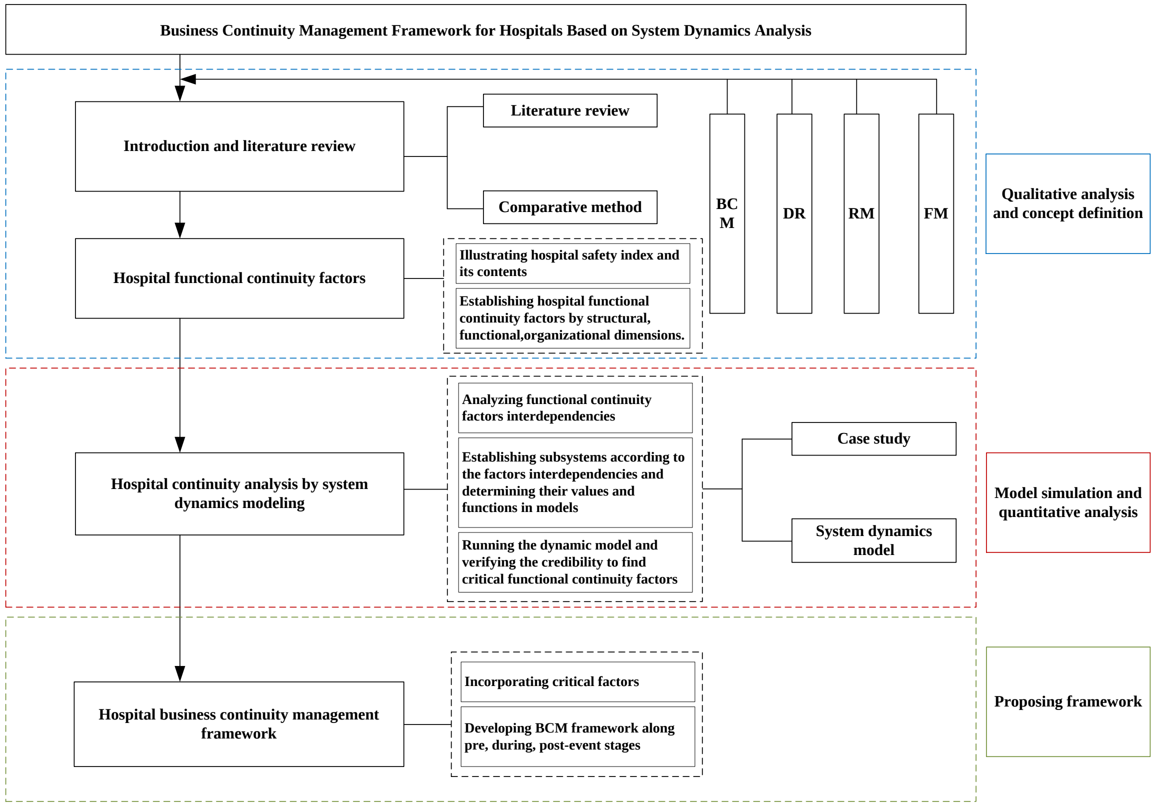


Figure 1 Research outline

CHAPTER 2: LITERATURE REVIEW AND REFERENCE THEORIES

The aim of this chapter is to review the literatures on the disaster resilience and preparedness of hospitals. Related basic theories consist of facility management, disaster management, business continuity management are illustrated and compared. This sets the stage to review hospital disaster resilience situations and research achievements based on these theories, including facility management model, risk/vulnerability assessment and mitigation strategies, disaster preparedness plans and business continuity strategies.

2.1 Hospital facility management practice

2.1.1 Facility management scope

The facility management (FM) has emerged as one of the fastest growing discipline in the past 40 years which adds value to core business of organizations. However, the scope of FM is still fuzzy with its multi-disciplinary nature that covers a wide range of various activities, responsibilities and knowledge. It is recognized that every aspect of an organization will be drawn into FM.

> *"FM is a profession which encompasses multiple disciplines to ensure functionality of built environment by integrating people, place, process and technology. Built environment is always referred to the terms of buildings, infrastructures, structures, space or a place*[6] *(IFMA)."*

In traditional views, FM was defined as the integral planning, construction and management of buildings and accommodation, services and resources which contributes to the effective, efficient and flexible attainment of organizational goals in changing environment. FM covers the whole lifecycle processes form the conceptual planning to construction of a building and utilization phase till the demolition of it. Gradually, FM has been considered as the management of noncore assets to support and increase the performance of main business components. In the framework proposed by Kincaid [7]

(1994), FM as a support role concerns three main activities which are property management/corporate real estate, property operations and maintenance and office administration. But FM is not simply the practice of managing various supporting services, it integrates knowledge of both physical facilities and soft management skills to work effectively. International Facility Management Association (IFMA), a leading association worldwide, gives a widely accepted general definition of FM, revealing the characteristics of integration of independent factors of built environment in a variety of positions. Multiple other professional organizations such as BIFM, EuroFM, FMA, IREM, Corenet and ASHE, also produce extensive FM knowledge, mostly reaching a common view that FM is responsible for varied services more than just building operation and maintenance with an operational and strategic role.

Since FM is management led, operational activities are expected to follow directives from strategic level. However, these two levels are understood to be equally important. FM scope should be integrated activities oriented with its management knowledge and operational procedures. Operational and strategic concerns are interrelated and must be developed in parallel to address both "software" (e.g. general administrative services) and "hardware" (e.g. building construction and maintenance)[8](Barrett, 2009). Usually the effective execution of "software" enables "hardware" to function. That is, the correct management plan enables the best facility implementation and operations. Figure 2 summarizes the main scope of FM work, including managing roles and operational activities. The higher the service or operation level to be achieved, the more sensitively connected FM must be every aspect of the organization. Concerns about support services for operations and activities should be driven by appropriate, relevant and adequate knowledge of facilities and management.

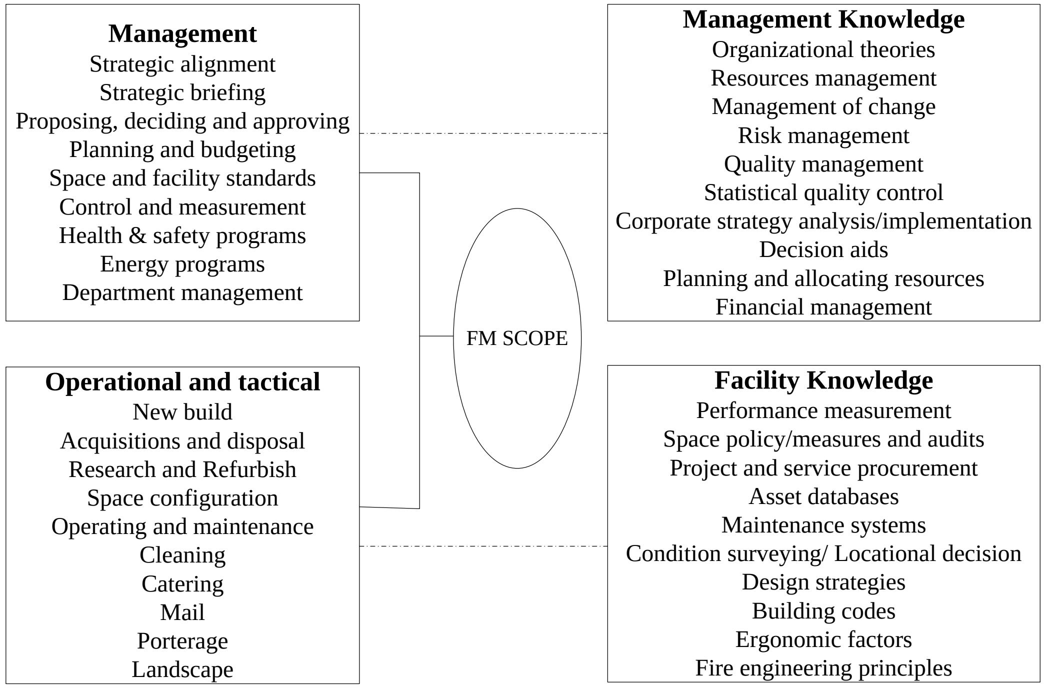


Figure 2 Main scope of FM work

Likewise, the knowledge based on healthcare FM, in particular, has grown with its different aspects including the development of management methodologies and operational structuring to resolve the complexity of the organization. Shohet and Lavy (2004) developed six core domains of healthcare facility management consisting of maintenance, building performance, supply service, strategic planning, information technology and risk management[9]. The literatures offer many definitions of these domains, which are shown in the following respectively:

1. Maintenance: Vatn el al.(1996) summarized that the main goal of maintenance, by taking a business-oriented viewpoint, is the maximization of personnel safety together with the minimization of the total cost, the environment threat and the risk of material damage[10]. Maintenance is defined as ensuring the continuous cost-effective fitness for the use of buildings at a specified building performance level. It is strongly connects to the building performance and cost effectiveness.

2. Building performance: Hattis described the performance concept relating to buildings, as a matrix in which one axis consists of building parts (e.g. materials, elements, components and systems) which make up the physical fabric of the building,

and the other axis consists of building attributes (e.g. structural safety and serviceability, health and hygiene, acoustics and durability) which form a user requirements and satisfactions 11 . According to Duffy 12 (1990) and Spendolini 13 (1992), building performance should be measured comparatively, usually, the benchmarking is recognized as representing the best practice for the purpose.

3. Supply service: According to Nesje's[14] (2002) survey at hospitals in Norway, he concluded that FM resource allocation has a high influence on operations and maintenance of facility performance. The supplying services are mainly achieved by combining in-house provision and outsourcing of FM services. Supply services means the best combination of in-house and outsourcing, covering tasks such as cleaning, security, gardening, catering and laundry.

4. Strategic planning: Strategic planning encompasses long-term planning, upgrading of existing facilities, rehabilitation, renovation and reconstruction (Butler, 1992)[15]. Hospitals make strategic responses to either perceived market changes or crisis created by not noting these changes early enough.

5. Information technology: The literatures review most emphasizes on the increased need and interest in the development of Information Communication Technology (ICT) in the healthcare FM area. ICT implementation in healthcare FM would be enhanced by the development of quantitative methods as well as the structured, strategic means aligned with the operations[16] (Waring, 2002).

6. Risk management: Healthcare facility is one of the most complex critical infrastructures in the communities with healthcare services performing in a dynamic environment. Hence, the risk management should be placed at high priority for any healthcare facilities[17] (Okoroh, 2002). Facility manager's principal duty is to identify, analyze and control the risks and uncertainty or potential hazards that threaten healthcare assets and patients and staff safety.

2.1.2 Building performance as the essential of FM

The vast majority of people work, live in, if not utilize, buildings every day. Alexander found that building performance is one of the most essential issues in the effective implementation of FM strategies. In the past, building performance usually dealt with issues such as energy efficiency, fire safety, comfort conditions and spatial efficiency[18] (Douglas, 1996). However, in many current existing buildings, increased expectations and demands are not met due to the accelerated building deterioration, inadequate maintenance in the fast-changing external environment.

Literature review shows that building performance evaluation is a central and necessary tool to in evaluating the efficiency of facility management. The interface between building performance and facility management is primarily the building diagnostics process, which is the systematic study and evaluation of building performance (Douglas, 1996). Building performance can be evaluated in terms of three components namely building functionality, building impact and building quality. Good buildings should be adaptive, durable, energy efficient and habitable. According to Abdul's case study of Australian public hospital, 11 regrouped factors (key performance indicators, KPI) which contributed to the excellence in building performance were evaluated[19] (shown in Figure 3). The factors are interrelated but have to be assessed independently for linking them together. It is found that healthcare facilities have certain characteristics that are intrinsic to their use which are required for pre-design evaluation and post occupancy evaluation.

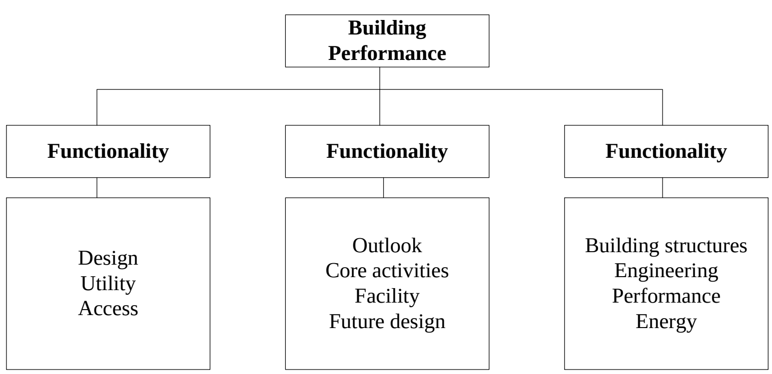


Figure 3 Framework for building performance assessment factors

Research done by Carthey (2009) explored climate change to the impact of extreme weather on healthcare infrastructure[20]. It has become a necessity to integrate disaster planning and management strategies in order to enable the healthcare services to be equipped to face the extreme weather events. Facility managers are normally involved in acquiring and installing air conditioning, electric power, UPS, emergency generators and fire suppression. When confronting disasters or emergencies, they are also responsible for evaluating the viability of the alternative facilities. Therefore common questions they should ask during healthcare facility building performance assessment are like do they have redundant power generating capabilities; do they have sufficient air-conditioning and secure facilities; is there enough parking; are their safety standards up to the facility standards; what kind of fire suppression do they have; what evacuation facility should they use. Making hospitals and health facilities safe from disasters is an economic requirement, and also a social, moral and ethical necessity.

2.2 Approaches to disaster management in hospitals

2.2.1 Disasters definition

In this thesis, the environmental hazard is limited to events originating in and transmitted through natural and built environments that lead to human death, economic damages and other losses above certain predefined thresholds of loss. In fact, thresholds of loss are used to define disaster (see definition of UN, ISDR 2009). Hazards and disasters are two sides of the same coin; each merges into the other and neither can be fully understood from the standpoint of either physical science or social science alone. They are linked to wider issues like global environmental change and many interacting factors that determine the prospects for sustainable development in the future. The main subsets of disaster threat/hazards are natural hazards and technological hazards. The reduce disaster hazards highlights the need for a better understanding of the worldwide coupled human-environment system [21] (Smith, 2013). A wider perspective ensures that hazards and disasters are now researched as complex issues. The probability of hazardous event can be placed from zero to certainty.

> *"Disaster is described as any occurrence that causes damage, economic disruption, loss of human life and deterioration in health and health services on a*

scale sufficient to warrant an extraordinary response from outside the affected area or community[22]. (UN, ISDR 2009)"

"The chief features of environmental hazards are: the origin of the event is clear and produces unknown threats to human life or well-being; the warning time is normally short and rapid-onset; most of the direct losses are suffered shortly after the event; the human exposure to hazards is normally due to the location of people in a hazardous area; the resulting disaster justifies an emergency response; the uncertainty and wide variations make risk assessment difficult. (Smith, 2013)"

The relationship between a hazard and its probability can be used to determine the overall level of risk. Risk is sometimes taken as synonymous with hazard, but risk has additional implication of the statistical chance of experiencing a particular hazard. Hazard is best view as a naturally occurring, or human-induced process or event with the potential to create loss, which is a general source of danger[23] (Kron, 2005). Risk is the actual exposure of human to a hazard, thus is defined as the product of probability and loss (Trucco, 2006)[24]. When hazards and risks cause an actual happening and people and properties are adversely affected, the event is identified as a disaster. Briefly, the sequence of events leading to a disaster is shown in Figure 4.

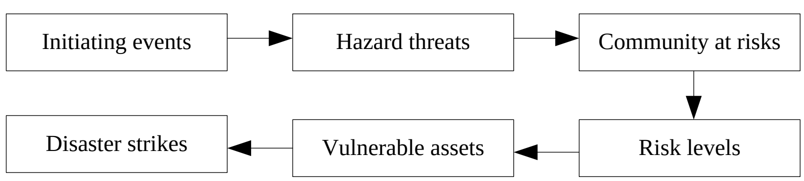


Figure 4 Sequence of events leading to a disaster

2.2.2 Approaches to manage disasters

Each natural hazard has different physical characteristics that create risks to life safety and property, consequently require different methods of effective control or management. Although every specific risk reduction activities are different due to each type of hazard, the management concepts can be similar. The most common approaches are risk management, crisis management, business continuity planning, disaster management and emergency management, as summarized in Table 1.

Table 1 Summary of various approaches to manage disasters

	Risk management	Crisis management	Business continuity planning	Disaster management	Emergency management
Implementation	Before disaster	During disaster	Before, during and after disaster	Before, during and after disaster	Before and during disaster
Key features	Prevention to stop impacts, ongoing proactive	Mitigation impacts and reactive coping	Recovery	Coping with disasters	Focus on specific events/ major events
Process	Risk identification, assessment	Recovery and response	Response, stabilization and business continuity	Preparedness, mitigation, response and recovery	Risk assessment, mitigation, response

Risk management

Risk management is conducted prior to disasters. Knight (2012) defined risk management as the culture, processes and structure that when combined, optimize the capacity to manage potential opportunities and adverse effects[25]. So the aim of risk management is to reduce and control risks before they unfold. In the healthcare context, risk management is a proactive approach to manage and reduce future uncertainties, while maintaining the quality of patient care. This involves identifying actual and potential risks, such as staff related risks, property risks and the analysis of their interdependencies[26] (Setola, 2009).

Crisis management

Crisis is also an adverse situation that will turn into a disaster. Unlike risk management, crisis management deals with the threats after they actually occurred[27] (Seymour, 2000). In particular, crisis management deals with problems mainly through the communication process, the exercise of authority, and the development of co-ordination[28] (Sweetser, 2007). Many research emphasized that immediate crisis response capacities of an organization, such as hospitals are only part of their adaptive capabilities required for long-term resilience. Usually, crisis management is incorporated within disaster recovery and business continuity planning.

Business continuity planning

Business continuity planning addresses organization's ability to continue its operations or business procedures after an incident, which highlights the timely recovery[29] (Wallace, 2010). Unlike other disaster coping approaches, the goal of a business continuity plan is to preserve and protect the essential elements and maintain an acceptable level of operation throughout a crisis and afterwards the company recovers[30] (Sahebjamnia, 2015). In hospitals, a business continuity plan dos not only focus on continuity of patient care, but critical operation procedures. Devlen (2009) argued that while most hospitals comply with disaster or emergency plans, they fail to identify their business continuity needs, it may be difficult to achieve wide application of continuity plan[31]. There is a lack of study specifically on business continuity plan of hospitals, however, it is a newly efficient way to increase hospital's ability to facilitate recovery initiatives.

Disaster management

The key purpose of disaster management is to cope with disasters before, during and after their occurrence [32] (Pearce, 2003). It is accepted by many countries that disaster management involves preparedness through response, from prevention, mitigation and readiness through relief, recovery and rehabilitation. Thus, disaster management is an ongoing process that occurs before, during and post disaster. Recently, the primary responsibility to manage disaster lies with the government and territory authorities and emergency response agencies, including hospitals and is promoted and coordinated through various national committees[33]. Traditionally, hospital disaster management plans failed to update regularly and most of them were prepared only by emergency department. However, the fact is that the complexity of disaster requires dynamic response and actions of every healthcare stakeholders. Nowadays, a shift has been appeared in disaster planning approaches to rethink disaster response for entire hospital.

Emergency management

The term limits its applicability to first responders[34] (Haddow, 2013). The approach is reactive and concentrates on scene triage and casualty distribution. Since the Wenchuan earthquake, China has improved government emergency management plans which focus on a comprehensive preparedness planning and responding to the community welfare needs caused by disasters. Emergency management gradually became similar to disaster management following basic principles of disaster management involving prevention, mitigation, preparedness, response and recovery[35] (LIU, 2009). Within healthcare context, emergency management needs the collaboration of representatives from public health, mental health, ambulances, hospitals, medical practitioners and emergency physicians to deal with immediate challenges.

2.2.3 Hospital disaster resilience

Developing the above approaches manage disasters requires the identification of resilience or vulnerability characteristics that influence organizations including hospitals. The concept of disaster resilience has gained importance in the light of increased frequency and impact of disasters, including natural disasters, pandemics and terrorism[36] (Zhong, 2015). The notion of hospital resilience encompasses the qualities that enable hospital staff and facility components to resist, respond, and recover from impact of disaster so that hospital will continuously provide “lifeline” services[37] (Achour, 2014).

There are only a few studies specifically on hospital resilience, while considerable work has been carried out for defining hospital capacity to cope with disasters with different perspectives, such as hospital safety, hospital preparedness, hospital business continuity and surge capacity. These concepts sometimes results in gaps and duplications. Thus this thesis aims to develop an integrated hospital resilience concept as starting point which consists of hospital core and noncore operations. Evidence of resilience measures was sought with instruments for measuring hospital capacity in the context of disasters. Several typical data extraction and evaluation of hospital assessment instruments to disasters are shown in Table 2. From these researches, hospital resilience is a comprehensive concept including structural components (e.g. facility safety), non-structural components (e.g. staff, medication and equipment), emergency medical functions (e.g. continuity of medical functions) and disaster management capacity (e.g. plans and procedures, crisis communications, community linkage). In order to be resilient, hospitals need to withstand the event, with both inherent strength and adaptive flexibility. At the same time, they are able to provide emergency medical functions and surge their capacity to respond to sudden increases in demand associated with disasters.

Table 2 Evaluation of hospital assessment instruments to disasters

Instrument name	Disaster type	Purpose of assessment	Type of tool
Hospital integration into community preparedness[38]	All hazards	Hospital community services linkages for response	Questionnaire
Hospital disaster preparedness[39]	All hazards	Hospital disaster preparedness and surge capacity	Survey and onsite visits
Hospital emergency readiness overview survey[40]	Chemical, biological, radiological or nuclear	Hospital chemical, biological, radiological or nuclear readiness	Online survey
Mass casualty disaster plan checklist[41]	Mass casualty event	Preparedness for mass casualty events in hospitals	Questionnaire
WHO hospital response checklist[42]	All hazards	Hospital administrator priority response actions	Checklists
PAHO safe hospital index[43]	All hazards	Hospital safety from disasters	Checklists
WHO safe hospital in emergencies and disasters[44]	All hazards	Hospital structural, non-structural and functional vulnerabilities	Checklists

2.3 Business continuity management as a new paradigm

2.3.1 Business continuity management definition and phases

Where BCM diverges from other disaster management approaches is its focus on preservation of business processes and timely recovery during disasters. Elliot et.al. have established evolutionary stages of BCM, beginning at its most preliminary stage at technology mindset, moving to the auditing mindset and finally the most advanced stage being the value-based mindset[45]. There are a number of definitions evident in both theory and empirical research in relation to BCM, which mainstream viewpoints are summarized in Table 3. This thesis adopts definition in British Standard BS 25999 for further study.

Table 3 Definitions of BCM

Author	Definition
Cerullo (2004)	Designed to avoid or mitigate risks, to reduce the impact of a crisis and to reduce the time to restore conditions to a state of "business as usual" [46]
Botha, et.al.(2004)	A complete process of developing measures and procedures to ensure an organisation's disaster preparedness[47]
Gibb, et.al.(2006)	A tool that can be employed to provide greater confidence that the outputs of processes and services can be delivered in the face of risk[48]
Pheng, et.al. (2010)	Identification and protection of critical business processes and resources required to maintain an acceptable level of business, protecting such resources and preparing procedures to ensure the survival of the organisation in times of business disruptions[49]
British Standard BS25999 (2011)	A holistic management process that identifies potential threats to an organization and the impacts to business operations that those threats, if realized, might cause, and which provides a framework for building organizational resilience with the capability for an effective response that safeguards the interests of key stakeholders, reputation, brand and value-creating activities[50].

Based on various definitions brought by different authors, different development cycles for BCM were simultaneously proposed. This thesis adopts the framework in Gibb's(2006) study. Each phase is illustrated in terms of a standard template which highlights the key activities that must be undertaken, and the associated inputs and outputs. The phases are (some of which will overlap) are program initiation, project initiation, risk analysis, selecting risk mitigation strategies, monitoring and control, implementation, testing, education and training and review. BCM program commencement include setting the scope, boundaries, aims and personnel responsibilities for BCM (British Standard BS25999). While the process required senior management support, staff throughout all levels of the organization must be engaged in order for BCM to be implemented effectively. Following the commencement, it is a critical stage to conduct an organization-wide risk assessment which involves assessment of organization's physical infrastructures and continued operations, during four main stages consisting of threat identification, calculation of likelihood, vulnerability assessment, and evaluation of solutions[51] (Griffiths, 2008). On a basis of risk assessment, the business impact analysis (BIA) identifies the critical business functions, their maximum allowable outage time, their recovery time objective, any sequential order required for operations to come back online and resources needed to achieve them.

> *"BIA is the backbone of the BCM process when an organization assesses the quantitative (financial) and qualitative (non-financial) impacts. The findings from BIA are used to make decisions concerning business continuity management strategy and solutions[52]. (Barnes, 2001)"*

Once the BIA is complete, the organization can identify the critical business functions. Continuity plans are constructed around each of these critical business functions or processes, to ensure adequate strategies and steps to restore the function as soon as possible in line with their interdependencies. It is recognized that most of the business continuity plans take the worst possible case scenarios which allows the organization to effectively handle severe incidents[53] (Hiles, 2007). Also Hiles suggest a comprehensive testing and training on business continuity plan as these actions will enhance a deep understanding by organization's stakeholders including external parts. As BCM is a continuous organizational process, plan review is a necessary component which ensures the capacity for trigger points such as changes to technology or business processes.

Throughout all the stages of BCM development and implementation, the organization must encourage and require extensive engagement, effort and resources to achieve properly.

2.3.2 BCM-based disaster management paradigm

Since BCM and disaster management result in gaps and duplications, this thesis will integrate their essential components to create a new paradigm for organization resilience particularly for hospitals. Traditionally as discussed above, disaster management consists of preparedness, response and recovery. The disaster preparedness usually develops a risk assessment and simulates various scenarios to exercise. Response plans include search and rescue of injured personnel. Recovery efforts cover a wide range of activities including restoration of building facilities and core business operations.

However, by integrating BCM, the goal of keeping continued operation can be justified through a new business continuity based disaster management paradigm, which is shown is Figure 5. Through BIA to identify critical business components, responders should be aware of the most significant part to preserve in the first time of disaster occurrence. While no immediate response (e.g. evacuation of people) is needed, the stabilization of event can help in formulation of a timely recovery strategy particularly to critical business components. Business continuity plan take role of plan B, saving core operations from disruption by unexpected events. The last stage is same as traditional disaster management model where the recovery strategy are fully presented and conducted.

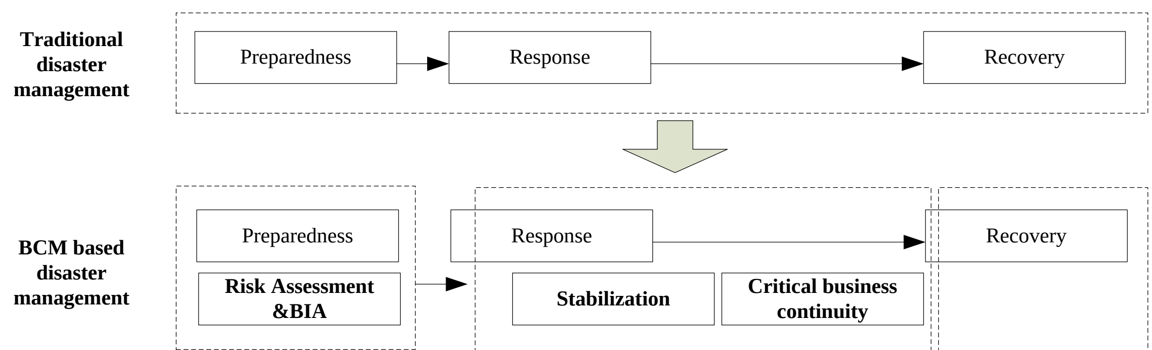


Figure 5 BCM based disaster management paradigm

Within a hospital context, the business continuity plan is invoked by both facility management team and business continuity management team. The facility management team, consisting of structural, electrical and mechanical engineers etc., are called to conduct the assessment of hospital building including equipment. When risk assessment is completed, the facility management team should report to BCM team about the potential extent of damage. Afterwards, BCM team should assess what critical assets and operations are impacted to accomplish a business continuity plan including tasks for recovery of critical elements in the organization. Both of FM and BCM teams should contain the pertinent information which can be collected and maintained and support the development of an assessment checklist. The business continuity plan should not be detailed instructions but rather information about the organization, critical assets which include people and resources, emergency plans for those critical components.

CHAPTER 3: HOSPITAL FUNCTIONAL CONTINUITY ANALYSIS

The aim of this chapter is to introduce the resilience factors of safe hospitals which come from hospital safety index developed by World Health Organization, covering structural, functional and organizational aspects. These resilience factors are described within facility management context, of which some follows building code and disaster preparedness laws.

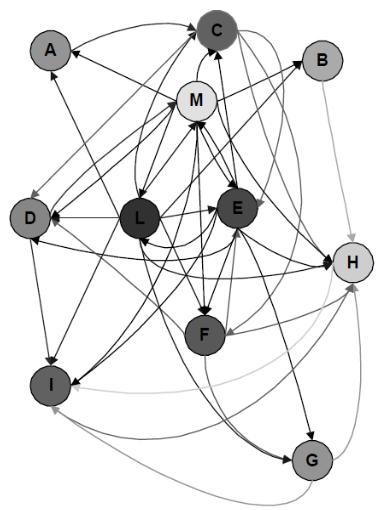
3.1 Hospital continuity resilience

3.1.1 Challenges facing facility losses

Overview of facility failure impact on hospitals

Healthcare facilities are one of the most complicated and critical facilities in any community. They are a key provider of health services as they monitor the well-being of society and prevent potential outbreaks. A lack of protection of building facility in resilience codes can pose additional risk to safety and continuity of operations in disasters.

This thesis mainly investigates in-house facilities, without neglecting the influence by outside national critical infrastructures and e-health services from remote structures. Each one of these facility components has been designed with a network-based structure in the presence of many functional relations. It is obvious that the network-linked facility components feedback mechanism will cause a cascade phenomenon if any of them is disrupted in a disaster, which largely modifies the behavior of any other component. The inoperability influence model for networked facility component for modern hospitals developed by Setola[54] is shown in Figure 6.There is a significant number of cases showing the impact of in-house facility failure in hospitals, which varied between inoperability of medical functions and coordination with outside and evacuation of hospital buildings. More case study problems experienced in hospitals[55] due to interruption of facility operation and supplies have been presented in Table 4. These problems have motivated organizations such as Federal Emergency Management Agency and Geohazards International to produce guiding documents[56], such as design code for improving hospital safety in earthquakes, floods and high winds, to help reduce risk associated with failure of facilities. Hence, it is important to better understand these vital facility components and how their failures affect the continuity of medical functions or core operations in hospitals.



A-water, B-medical gas,
C-air-conditioning, D-telephone
E-IP network, F-IT infrastructure
G-electric case history
H-bio-medical apparatus monitor
I-medical alarms
L-electric network
M-infrastructure monitor

Figure 6 Inoperability influence model for networked facility component for modern hospitals

Table 4 Samples of hospital facility impact and consequence

Hospital	Hazard	Impact	Consequence
NYU hospital	Hurricane	Loss of electric power	Evacuation of 200 patients
Group of hospitals in Chile	Earthquake	Loss of power and insufficiency of backup power; interruption of telecommunication systems; loss of municipal water	Inoperability of medical functions and coordination with the outside
Gloucestershire hospital	Flood	Water contamination	Inoperability of medical functions and cease of activities
Christian and Shiu-Tuan hospitals	Earthquake	Damage to fuel system	Blackout
Kobe University medical college	Earthquake	Damage to high raised water tank	Flooding, blackout and evacuation of the facility
Group of hospitals in Iowa	Flood	Water loss	Nearly all phases of patient care and facility operation were affected.

External critical infrastructure vulnerability

National critical infrastructure failures can be driven by the intensity of disasters or also by its own vulnerability. Infrastructure vulnerability is due to lack of expenditure and the increasing number and severity of climate change driven natural hazards in many countries. Governments have realized the significant deficiencies in the critical national assets since the occurrence of big disaster these years. In winter, UK consumes approximately 60 gigawatts of electric power, most of which are generated by 30 large power stations (ICE, 2010). Many of these power stations are located in vulnerable areas such as the Dungeness power plant which is built few meters above the sea level on an unstable geological formation, and the hundreds of power substations and water treatment plants that have been built in floodplain areas. Some of the infrastructure has been very close to failure during recent events.

Low performance of backups

International organizations such as WHO and PAHO recommended that hospital facilities have alternative suppliers and duplicate items to provide a certain level of independence form external supply networks. Consequently many hospitals have been equipped with alternative supply systems, which increased their resilience and secured the continuity of hospital business operations. There are many alternative resources, but most used are Uninterruptible Power Supply (UPS) systems and power generators. UPS systems have been used in many facilities and charged with commercial power or fuel power generators. However, experience has demonstrated that commercial power automatically shuts down in earthquakes for safety reasons or as a result of networked damage which underlines the risk of power interruption. The performance of power generators has been a major issue in hospitals for many decades. Also generators operating disruption are largely due to unsatisfactory cooling systems which depend on water supply and fuel systems. Thus a series of interrelated backup facilities need to be prepared for disasters.

3.1.2 Hospital resilience definition

Based on previous literature review of disaster resilience, it is induced that hospital resilience is the quality or capacity that enables hospital staff and facilities to withstand disaster impacts with inherent strength and adaptive flexibility, at the same time providing continuous life-support services.

The extent and severity of damage caused by an adverse event is inversely proportional to the level of resilience of a facility. A resilient hospital is a facility whose services remain accessible and functioning at maximum capacity and in the same infrastructure, during and immediately following the impact of a natural hazard. Hospital resilience highlights its business continuity during disasters. The continued operation of hospitals provides reassurance that the essential institutions of society have not broken down and allows the community assistance to be coordinated. In this context, it is clear that the concept of resilience must encompass and address infrastructure and cross-cutting themes of hospital disaster preparedness, representing facilities: in which urgently needed medical care remains accessible and functioning at full capacity (or at minimum, operating as a sufficiency-of-care facility); capable of providing the reassurance and medical leadership needed by the general public in times of crisis; and with structured relationships that establish an interface among local and regional entities involved in a community-wide disaster response. The mechanism of resilience building includes facility-oriented and community-integrated disaster responses.

3.2 Hospital safety index

3.2.1 Current applications

Hospitals and health facilities play a critical role in times of emergency and disasters. It is imperative that they remain structurally sound and fully operational at such times. To ensure that hospitals and health facilities can withstand emergencies and disasters, an assessment of their vulnerabilities is most significant. These vulnerabilities may be structural (load-bearing system), non-structural (architectural elements, installation and equipment and systems) and operations.

Hospital safety index, developed by PAHO Disaster Mitigation Advisory Group, is a basis reference for evaluating hospital safety in disaster situations, formulating the sets of structural, non-structural and functional indicators. It is important to point out that the hospital safety index was built with the knowledge of professionals from different specializations and that consensus was achieved following intense discussions and its application in a few health facilities. Experts recognize that it is the best assessment system of rapid and comprehensive hospital resilience evaluation that exists. However, it is still probable that the hospital safety index needs to be revised in the near future.

Applying the hospital safety index into hospital assessment can yield useful information about a facility's strength and weakness. There are three objectives of using: assessing existing hospitals and health facilities in terms of structural, non-structural and functional vulnerabilities; advocating for construction of a new hospital or health facility that could withstand any emergency or disaster; planning for renovation and retrofit of hospitals and health facilities to ensure their resilience, safety and continuous operations in times of emergency and disasters. The main target audiences are the governments, health authorities, financial institutions and disaster management organizations that will use the framework as a guide for the development and implementation of hospital safety assessment at national, subnational and facility levels. The wider audience includes all stakeholders in safe hospitals across many sectors, as well as hospital managers and staff who can use the framework to guide projects and activities for making hospitals more resilient and better prepared for emergencies and disasters. Once the evaluation is completed, the evaluation results should be presented to the hospital board of directors. The hospital staff is responsible for making the changes needed to improve hospital safety level within a time frame.

3.2.2 Hospital safety index by categories

During emergencies or disasters, hospitals and other health facilities must remain safe, accessible and functioning at maximum capacity in order to help save lives. They must continue providing critical services such as medical and nursing care, laboratory and other health care services as well as respond to increased requirements related to the emergency. A safe hospital must remain organized with contingency plans in place and health personnel trained to keep the network operational. Making hospitals safe involves knowledge of the many factors that contribute to their vulnerability during an emergency or disaster such as the building's location, design specifications and materials used contribute to the ability of the hospital to withstand adverse natural events. There should be involvement of various sectors such as hospital operations planning, finance, public services and architecture and engineering in determining the vulnerability of hospitals and addressing these concerns. The design in the construction of hospitals and health facilities should follow building codes, fire safety guidelines and other risk-reduction measures. The non-structural and functional vulnerability of existing facilities should be improved. In the advent of emergency or disaster, damage to nonstructural elements can force hospitals to halt operations. Lifelines such as electric power, water and sanitation and waste treatment and disposal also are important for continuous operations. All of these potential vulnerable factors are divided into three categories:

① Structural: Structural indicators are crucial for the building to withstand adverse natural events. These include the building location; design specifications and materials used for the hospital or health facility.

② Non-structural: Non-structural indicators are essential for the daily operations of hospitals and health facilities. If these are damaged, they will not be able to function and even may cause physical injury to patients and personnel. These include architectural elements such as ceilings, windows and doors; medical and laboratory equipment; critical lifelines (mechanical system, electrical system and plumbing system installations); and safety and security issues.

③ Functional: Functional indicators are important for the continuous operation of hospitals and health facilities. These include site and accessibility; internal circulation and interoperability; equipment and supplies; emergency standard operating procedures and guidelines; logistic system and utilities; security and alarm; transportation and communications systems; human resources; and monitoring and evaluation.

3.3 Hospital functioning continuity factors

By referencing hospital safety index, this thesis proposed similarly three parts of hospital resilience factors, which are functional supporting resilience factors, medical function resilience factors, and organizational resilience factors.

3.3.1 Functional supporting factors

Functional supporting factors encompass all the structural and architectural physical elements related to hospital facility management to withstand disasters, which support the medical services to be smoothly delivered without interruption.

Structural physical elements should be appropriate to the building location and the natural hazards common in the country. The terrain where the hospital or health facility is located may indicate possible threats such as flooding in valleys or landslides along slopes. Identification of the location and any potential hazards should be addressed by proper measures to minimize damage to structures. There should be a provision for proper rainwater drainage in areas prone to flooding and using lighter and safer roofing material in earthquake zones or sturdier material for typhoon-prone sites. Other standard structures such as access to people with limited mobility also must be in place. Ramps must be located in proper places for transporting patients on beds and in wheelchairs. Failure to do this may compromise the safety of these people, especially if the health facility must be evacuated. As evidence of building structural integrity, hospitals and health facilities should have the following available at all times: ①approved construction plans showing that the building has been designed by architecture and engineering professionals who will be liable and responsible for the integrity of the building in all its architectural and engineering aspects; ②as-built plans showing the building’s interiors, knowledge of which is necessary for maintenance, upgrading and renovation; ③updated as-built plans or records of renovations and reference documents for succeeding design changes and renovations; and an occupancy permit that certifies a building’s compliance with applicable building codes and other laws and shows that it is in condition suitable for occupancy.

Basic considerations regarding architectural elements are similar to the structural indicators. They share the same goal, that is, the building structure will be able to withstand any physical stress that might be caused by natural hazards such as a typhoon, floods, landslides and earthquakes. Considerations related to the equipment and lifelines focus on their location and whether they are anchored properly. The presence of heavy equipment or machines changes the building's structural integrity. These must not be placed on upper floors or on weak floors because it might result in the collapse of structures even at the slightest movement caused by an earthquake or the normal wear and tear of buildings through the years. Heavy equipment and machines also should be firmly anchored to a structural element of the building or its foundation. This is to prevent its moving, sliding or falling, which could cause structural damage or physical injury to patients and personnel.

Availability of utilities, such as water supply, electricity and air-conditioning is crucial to the daily operation of hospitals and health facilities. Water supply should be safe and potable and there should be a reliable alternate source of water such as a rural water system, local fire station or storage tank. Additional liters are needed for laundry, flushing toilets and other utilities. There also should also be a reliable alternative source of power for emergency lighting and operation of essential equipment in the event of power failures. Ideally, there would be a generator capable of supplying at least 50%-60% of the facility's normal electrical load. This should be located on the premises but not adjacent to the operating and ward areas. Emergency lights should be available for use between the interruption of the power supply and connection to a generator to light important areas inside the health facility such as, stairs and hallways, the operating room, emergency room, nurses' stations and cashier area. They should not be used as substitutes for the generator.

Functional supporting resilience factors are presented in Table 5.

Table 5 Functional supporting factors and descriptions

NO.	Functional supporting resilience primary factors	Factors descriptions
1	Location	The entire hospital facility is not located in a hazardous area.
		Building has appropriate provisions for addressing hazards.
2	Accessibility	Building has access to more than one road (alternative routes) and has separate entrance and exit routes.
		Building has available covered walkway to interconnect service areas.
3	Design	Building structural members (foundation, columns, beams, floors, slabs, trusses) and non-structural members (glass walls, doors and windows) conform with requirements for strong winds and earthquake.
4	Construction management	Complete set of as-built construction drawings and readily available for reference purposes.
		Construction materials thoroughly checked by a materials/quality assurance/quality control engineer during construction for conformance to specifications
		Building alterations conducted with proper consultation with engineers and a review of the original plan of the building
5	Building structures	No major structural cracks on structural members.
		Cabinets, shelves, appliances and equipment are properly anchored.
		Structures built with fire-resistant and nontoxic materials
		Regular quality inspection and maintenance of the building structures are conducted.
6	Architectural elements	Non-structural elements of roof, ceilings, doors and entrance, windows and shutters, walls, divisions, partitions, ornaments, facade, plastering, floor covering, are securely fastened to building main structures and made of fire-resistant construction materials.
7	Electrical system	all electrical systems and rooms protected with appropriate chemical automatic fire suppression units
		Generator housing or powerhouse protected from natural and man-made disasters; made of reinforced concrete; elevated from the ground line; generators and other vibrating equipment can be fixed by special brackets that allow movement but prevent them from overturning.

		Emergency generator has the capacity to meet priority hospital demands (provision for backup electrical system to include operating room, intensive care, pathways); functional electrical and emergency lights with battery backup in all critical areas.
8	Water supply system	Water distribution system (valves, pipes, connections) are free from leaks and harmful agents; Water storage tank has safe installation and location
		Water tank storage has sufficient reserve to satisfy the hospital demand for three days at all times.
9	Fire emergency system	Alarm, detection and extinguishing systems have interconnected automatic fire alarm system, automatic heat and/or detection system and automatic fire suppression system are complete.
		It has fire safety program with standard procedures.
		Emergency lighting facilities maintain the specified degree of illumination in the event of failure of the normal lighting for a period of at least one hour. Egress is illuminated at all points.

3.3.2 Medical function factors

Medical function factors are those safety actions during delivering medical services and managing medical equipment. Medical function issues are related to handling and storage of chemicals and potentially hazardous substances. Improper handling and storage of these chemicals and substances may cause injury by virtue of their inherent toxicity or by causing chemical reactions that could be appropriate training for personnel handling these chemicals and hazardous substances. Safety guidelines for proper handling and storage should be disseminated and implemented. For example, the proper arrangement and grouping of chemicals should be followed strictly to prevent accidental chemical reactions. Proper labelling with a manufacturer’s warning and providing appropriate instructions on what to do in the event of accidental contact with these substances are important aspects of safety guidelines. The use of material safety data sheets (MSDS) also should be encouraged, although different countries have different regulations regarding their use. These also should be official documents that are used to disseminate important chemical safety information to workers, emergency responders and the public. Security of the building and the general safety of all of the patients and personnel inside the hospitals and health facilities also should be addressed.

Medical function resilience also should be in place for estimating supplies and drug requirements, maintaining an inventory, storing and stocking and issuing and controlling. The medical gas supply is vital for the survival of some patients in the health facility but is also a source of danger if not properly maintained. The tanks or medical gas pipes must be inspected regularly to ensure that they are still in good condition. In cases of piped-in gases, there should be safety valves installed to prevent leaks.

Medical function factors are presented in Table 6.

Table 6 Medical function factors and descriptions

NO.	Functional supporting resilience primary factors	Factors descriptions
1	Medical gas system	Medical gases properly stored and secured in well-ventilated areas or compartmented storage areas. Safety of medical gas distribution system (valves, pipes, connections) is ensured.
		Tanks bear an intact safety seal from the supplier.
		Available backup oxygen tanks in case of emergency patient evacuation are ensured.
		There are functional pressure gauge, fittings and use of standard pipes.
2	Medical and laboratory equipment and supplies	Equipment safety in operating room and recovery room
		Safety of radiological equipment and other support devices
		Safety of medical equipment in emergency rooms/intensive care units/wards
		Safety of medical equipment in pharmacy departments
		Safety of medical equipment in sterilization units
		Safety of equipment and other support devices in nuclear medicine department and radiation therapy units
		Proper segregation and storage of hazardous materials and chemicals as well as safe and well-secured electrical outlets are ensured within all medical function departments.

3.3.3 Organizational functioning factors

Organizational functioning factors are inspected within logistic systems, safety and security systems as well as components related to hospital internal circulation and interoperability.

Communication is vital to the success of all coordination efforts. A public information center should be established where the public can go to request information concerning family members. The center should be coordinated by a social worker and staffed by the health facility's personnel or volunteers. The health facility's disaster plan should provide for the continued functioning of the public information center during disaster situations. Public education is best integrated into the health facility's disaster plan. The public must be informed of the types of possible disasters and told how they should react during those emergencies. This would help the institution to mitigate the effects of the disaster.

Human resources remain the most important among available resources in a hospital or health facility. Personnel should be adequately prepared for emergencies and disasters. There also should be organized groups of people or committees who would be responsible for planning and responding if there is an emergency or disaster. The emergency planning committee should clearly define situations that would warrant activation of a disaster plan. The health facility could create an onsite disaster response team, depending on the availability of physical elements and human resources. The basic prerequisite for personnel on this team is that they be properly trained in first aid and that they have the necessary means to move immediately to the disaster scene. There also should be coordination with the local fire department for guidelines regarding proper placement of fire detectors and firefighting equipment. Other important training includes basic life support, advanced cardiac life support and familiarity with the Incident Command System (ICS) and a mass casualty incident (MCI). There also should be fire drills and simulation exercises once or twice a year.

Proper monitoring and evaluation also is needed, which includes post-incident evaluation of emergencies or disasters that have been responded to an annual fire drill simulation exercises to ensure that hospitals and health facilities are safe for health emergencies.

Organizational functioning factors are presented in Table 7.

Table 7 Organizational functioning factors and descriptions

NO.	Functional supporting resilience primary factors	Factors descriptions
1	Internal circulation and interoperability	It has proper zoning of service areas e.g. departments most closely linked to the community are located nearest to the entrance (OPD, ER, administration, primary health care); departments that receive their workloads from the wards or inner zones should be located closer to these zones (radiology, laboratory)
		General service areas such as power plant, boilers, water storage facilities, laundry area and pump house are located in separate structures; laboratory, radiology and radiotherapy-medicine facilities are restricted areas.
		Areas to be converted to spaces for patients during disasters are properly identified with adequate lighting, electrical outlets, water supply and lavatories or bathrooms.
2	Logistic systems	Procedures are standardized for resource mobilization (funds, logistics, and human resources) to include shifting of duties during emergencies and disasters and to expand services, spaces and beds in the event of a surge of patients.
		There are stockpile of emergency medicines and supplies.
		Manuals management for electrical supply and backup generators; drinking water supply and alternate source of drinking water; fuel reserves; medical gases; standard and backup communications systems; wastewater treatment; solid waste treatment; fire suppression
3	Safety and security systems	There is accessible, tested, updated and disseminated hospital emergency preparedness, response and recovery plan that includes a hazard prevention and mitigation plan, vulnerability reduction plan and a capacity development plan including the systems, guidelines, standard operating procedures and protocols.
		Equip ambulances for transport of casualties from the field to the

		hospital, for moving patients to other facilities in cases of referral or overload or for evacuating and relocating a hospital service.
		Coordinate with local officials to assist the hospital during emergencies and disasters. There are fixed procedures and information center for communicating with the public and media.
		Contingency plans for needed medical treatment during different types of disasters, including diseases with an epidemic potential
		Conduct fire drills at least twice a year and conduct simulation drills or exercises at least annually.
		Post-incident evaluation of emergencies or disasters for which there has been a response.

CHAPTER 4: HOSPITAL FUNCTIONAL CONTINUITY MODELING AND BUSINESS CONTINUITY MANAGEMENT FRAMEWORK

The aim of this chapter is to assess the interdependencies of resilience factors to identify critical hospital continuous operational capacity indicators through a System Dynamics model. The overall hospital continuity system is composed by three dimensions of hospital functional continuity factors as described in Chapter3. By running different scenarios, the results are compared and critical factors are found. Finally, a business continuity framework is proposed by incorporating these critical factors.

4.1 Hospital functional continuity modeling: system dynamics

4.1.1 Modeling method

Risk assessment methods have traditionally focused primarily on the technical dimension. Researchers describe disaster impacts using a sequential model which represents the linear succession of a set of events linked by cause and effect, such as failure mode effect analysis (FMEA), fault tree analysis (FTA), failure mode effect & criticality analysis (FMECA), and preliminary hazard analysis (PHA). However, these linear models do not take into account interactions between risk, vulnerability or resilience factors, and do not adequately address human and organizational factors. This thesis aims to investigate the dynamic interactions between hospital functional continuity factors to provide a decision-making tool that allows controlling of safety in a hospital. A case study is implemented to simulate the integration of prevention measures in the system.

System Dynamics is the theory of system structures that deals with the causal interactions between components for analyzing their dynamic behaviors. System dynamics is a modeling method that allows a system to be represented in terms of feedback. Forester[57] (1961) has developed four steps to create a system dynamics model. The first step is the articulation of the problem, defining the purpose of modeling and identifying the entities, interactions and behaviors to highlight. The second step is to describe the causal relationships between these entities, by building the causal (or influence) diagram. Causal diagrams represent major feedback mechanisms, which reinforce (positive feedback loop) or counteract (negative feedback loop) a given change in a system variable. The third step corresponds to the introduction of stock variables and flow in the system by building a stock-flow diagram. This diagram is a quantitative model and introduces the time dimension by considering the rate of change in the level of variables (stock variables and flow) over time. This model consists of three types of element: stock (or level) elements (also called state variables); flow elements; and auxiliary variables and constants. The fourth step is to formulate simulation models. The laws that govern the evolution of each variable take into account the values of the variables that influence it and from which it receives information. The equations that simulate the behavior of the system over a period of time, using initial values for state (stock) variables, generate the dynamic behavior of the system. In this way a system dynamics model allows examination of a period of behavior of complex systems.

This thesis aims to construct three subsystems (i.e. functional supporting resilience, medical function resilience and organizational resilience) of a complex hospital continuity system to reflect the behavior of each resilience factor. It is constituted by functional supporting subsystem, medical function subsystem, and the continuity safeguarding subsystem. The resilience factors are represented as different types of variables in the stock-flow diagram with laws or equations for simulation. The hospital continuity system dynamics variables and parameters corresponding to each resilience factors are shown in Table 8. The causal relationships of these functioning continuity factors are presented in Figure 7.

Table 8 hospital functional continuity variables in system dynamics model

Subsystem	Resilience factors	Symbols	Type of variable
Functional supporting subsystem (SUP)	Location impact, Design impact, Construction management impact, Building structures impact, Architectural elements impact, Electrical system impact, Water supply system impact,	*SUP(S),SUP(D), SUP(C),SUP(B), SUP(A),SUP(E), SUP(W) respectively*	Auxiliary
	Functional supporting subsystem operational level	*SUP*	Auxiliary
Medical function subsystem	Medical function subsystem operational level	*MED*	Auxiliary
	Medical gas supply impact and	*MED(E)*	Auxiliary

(MED)	medical equipment supplies impact		
Continuity safeguarding subsystem (CON)	Continuity safeguarding subsystem operational level	*CON*	Level
	Logistic systems efficiency	*CON(Q)*	Auxiliary
	Emergency backup supply	$CON(Q_1)$	Constant
	Coordination within emergency groups	*CON(C)*	Auxiliary
	Emergency training and drills	*CON(T)*	Auxiliary
	Hospital continuity organizational culture impact	*CUL*	Constant
	Business impact analysis and risk assessment frequency before disasters	*RM*	Auxiliary
	External critical infrastructure/lifeline	*CON(L)*	Constant
	External public rescue team assistance	*CON(R)*	Constant
	Fire engineering system impact	$CON(F)$	Auxiliary
	Site accessibility impact	$CON(S)$	Auxiliary
	Potential hazards	*HAZ*	Lookup

In this thesis, Vensim software[58] as a common platform is applied to system dynamics. Vensim is simulation software relationships and the structural elements of a diagram using a model equation. It is characterized by a visual output; system behavior and system status are shown graphically. It is useful for comparative analysis. The features of the software are outlined in their reference manual.

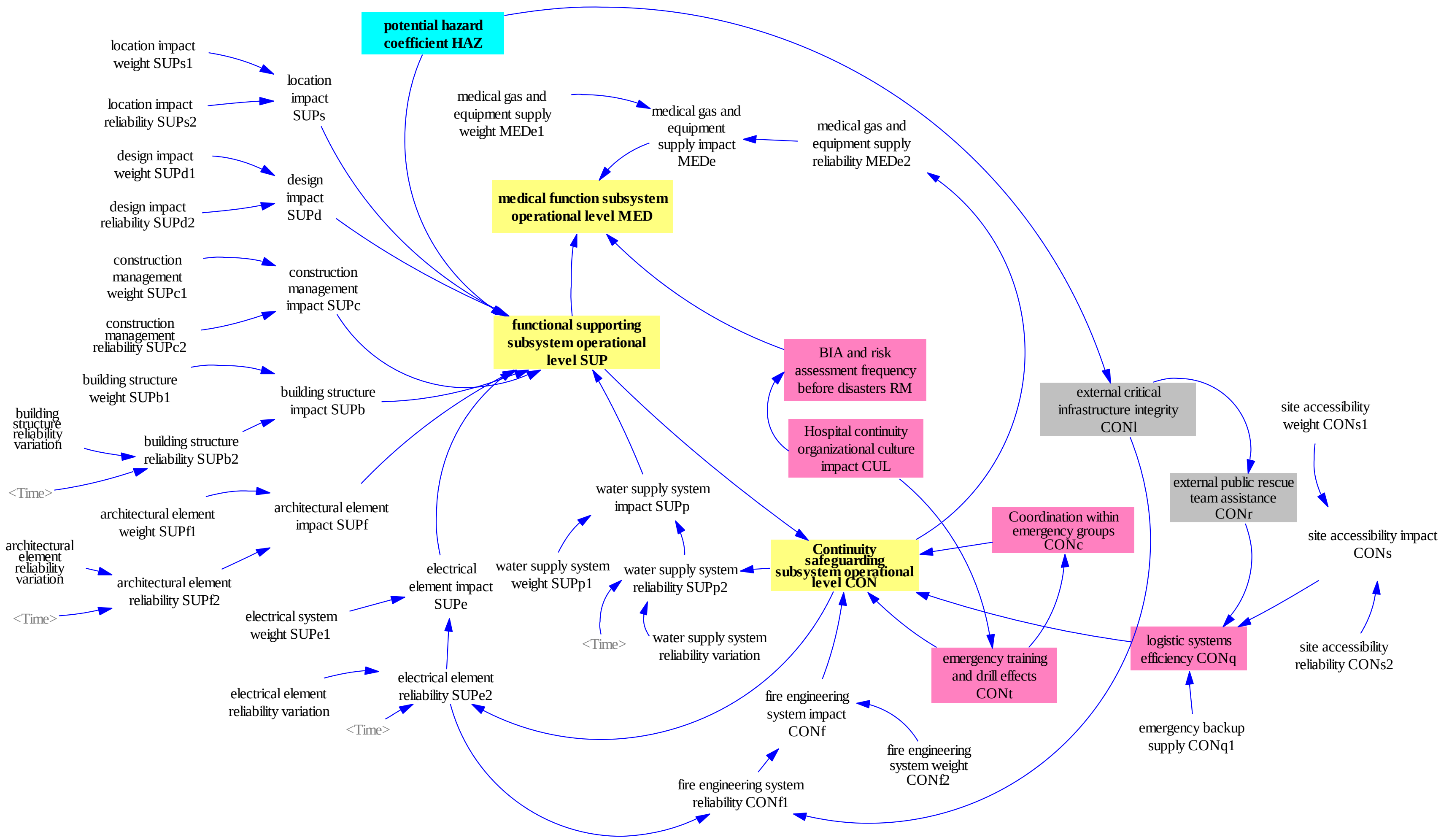


Figure 7 Hospital continuity system dynamics model resilience factors causal diagrams

4.1.2 Functional supporting subsystem

According to the functional supporting subsystem causal diagram in Figure7, each resilience factor is described in its equation or law by calculating the reliability R/ability to function at a specified moment or interval of time (operation levels). The reliability models mainly are presented in three ways: the linear series reliability model (see Equation 1), parallel reliability model (see Equation 2) and standby reliability model (see Equation 3).

Equation 1 Linear series reliability model

$$R = R_1 * R_2 *\ldots* R_n = \prod_{i=1}^{n} R_i$$

Equation 2 Parallel reliability model

$$R = 1 - \prod_{i=1}^{n} (1 - R_i)$$

Equation 3 Standby reliability model

$$R = R_1 + [(1 - R_1) * R_2 + \ldots + (1 - R_1) * (1 - R_2) *\ldots* (1 - R_{n-1})] * R_w$$

In this thesis, R_i is the reliability of each subsystem component which means the status of "Location", "Design", "Construction management", "Building structures", "Architectural elements", "Electrical system", "Water supply system". The reliability models may incorporate predictions such as the value of R based on failure rates taken from historical data. With a reference to time-sequence failure theory, the prediction of each R_i can be calculated by failure rate equation (see Equation 4). While the (input data) predictions are often not accurate in an absolute sense, they are valuable to assess relative differences in design alternatives.

Equation 4 Failure rate equation

$$R_i(t) = e^{(-\mu t)}$$

Hence, in the functional supporting subsystem, the risk impact $SUP(x)$ of "Location", "Design", "Construction management", "Building structures", "Architectural elements", "Electrical system", "Water supply system" is constituted by two components: the influential weight of each resilience factor $SUP(x_1)$ and their reliability $SUP(x_2)$. The robustness equation is interpreted in Equation 5.

Equation 5 Functional supporting robustness equation

$$SUP(x_2)=e^{(-\mu t)}$$

$$SUP(x)= SUP(x_1) * SUP(x_2)$$

By integrating all the resilience factors in the functional supporting subsystem, the general resilience of functional supporting subsystem SUP or its operating level is presented in the Equation 6. When hospital is located in a disaster prone area where the disaster prone level is described by $\propto_2$ and its building structure is destroyed over certain scope with a threshold, $\propto_2$, the overall hospital facility operation is totally disrupted and the resilience of SUP is 0.

Equation 6 General operating level of functional supporting subsystem SUP

$$SUP = \begin{cases} 0 & , \quad SUP(B) <\propto_1 \text{ and } SUP(S) <\propto_2 \\ (1 - \prod \frac{100 - SUP(x)}{100}) * 100 * HAZ, & SUP(B) \geq\propto_1 \text{ or } SUP(S) \geq\propto_2 \end{cases}$$

where: $SUP(x)$ *includes* $SUP(S),\ SUP(D),\ SUP(C),\ SUP(B),\ SUP(A),\ SUP(E),\ SUP(W)$; $SUP(x_1)$ *includes* $SUP(S_1), SUP(D_1), SUP(C_1), SUP(A_1), SUP(F_1), SUP(E_1), SUP(W_1)$; $SUP(x_2)$ *includes* $SUP(S_2), SUP(D_2), SUP(C_2), SUP(B_2), SUP(A_2), SUP(E_2), SUP(W_2)$.

4.1.3 Medical function subsystem

In the medical function subsystem, the main components are the medical gas supply and medical equipment supplies. Similarly, the medical gas supply and medical equipment supplies impact $MED\ (E)$ is constituted by its influential weight $MED\ (E_1)$ and $MED(E_2)$ (see Equation 7). It is also pointed out that the resilience or operating level is primarily determined by the functional supporting subsystem resilience and continuity safeguarding subsystem in a disaster scenario (as seen from Figure 7). In order to guarantee the continuous medical function operation, there is a minimum threshold for its supporting function and pre-event risk management frequency, that is, SUP cannot be less than 70% and pre-event risk management implanting level RM cannot be less than

θ_1 to ensure the medical functions (of which these threshold were suggested by participants in the case interview). Thus the general operating level of medical function subsystem MED is calculated with Equation 8.

Equation 7 Medical gas supply and medical equipment supplies

$$MED(E) = MED(E_1) * MED(E_2)/100$$

Equation 8 General operating level of medical function subsystem MED

$$MED = \begin{cases} SUP * MED(E), RM \geq \theta_1 \text{ and } SUP \geq 70 \\ SUP \qquad\qquad\quad , RM < \theta_1 \text{ or } SUP < 70 \end{cases}$$

4.1.4 Continuity safeguarding subsystem

Continuity safeguarding subsystem is developed to measure the capacity of hospital organizational quick response to disasters including the emergency logistic systems efficiency, emergency backup supply, coordination within emergency groups and emergency plan execution effectiveness. External resources such as public rescue team assistance and external critical lifeline infrastructures also have a direct impact on the procedures of emergency response and business continuity programs. Usually Disaster Medical Assistance Teams, groups of trained medical and non-medical personnel with various combinations that on the optimal conditions are dispatched to disaster sites to work self-sufficiently. Within a hospital organizational disaster program, fire engineering system capacity, which depends on a continuous functional supporting subsystem and accessibility of a hospital building, contributes positively to an effective disaster response action and emergency training and drills. Conducting a successful emergency training and drills will be influenced by penetrating to public deep RM and business continuity organizational culture. Related equations are shown as below:

Equation 9 Relations among "Emergency training and drills" CON(T), "Coordination within emergency groups" CON(C) and "Conducting business impact analysis and risk assessment before disasters" RM

$$CON(T) = CUL * \beta_1;\ CON(C) = CUL * \beta_2;\ RM = CUL * \beta_3, \text{ where } \beta_1, \beta_2, \beta_3 \text{ are coefficient.}$$

Accessibility to the hospital facility is a fundamental stepping-stone for rapid and efficient rescue work and emergency logistic delivery. Hence, accessibility $CON(S)$ is applied to calculate “Logistic systems efficiency $CON(Q)$”. An easier accessibility also enables a quicker delivery of essential emergency goods by internal or external organizations. When hospital itself stores enough emergency backup supply more than 50% of all needed, the “Logistic systems efficiency” will reach 100% by both external and internal resource supplies (of which these threshold were suggested by participants in the case interview). Hence, the “Logistic systems efficiency” equation is shown as below:

Equation 10 Logistic systems efficiency equations

$$CON(Q) = \begin{cases} CON(Q_1) * CON(R)^\wedge\frac{CON(S)}{10} & ,CON(Q_1) < 50 \\ 100 & ,CON(Q_1) \geq 50 \end{cases}$$

Where: $CON(S) = CON(S_1) * CON(S_2)$; $CON(R) = CON(L) * \beta_4$; $CON(L) = 1 - HAZ$

Fire engineering system is a fundamental part of the whole disaster preparedness plan and continuity program, which is dependent on a robust electrical facility operation. This thesis assumes that if external critical lifeline is destroyed more than 50% or more than 50% of the functional supporting subsystem cannot operate, the functionality of fire engineering system is the same as the electrical facility functional level, otherwise, it will perform 100% of its full capacity (of which these threshold were suggested by participants in the case interview).

Equation 11 Fire engineering system impact

$$CON(F_2) = \begin{cases} SUP(E_2)\ , CON(L) < 50\%\ or\ SUP(E_2) < 50 \\ 100\ , \quad CON(L) \geq 50\%\ and\ SUP(E_2) \geq 50 \end{cases}$$

$$CON(F) = CON(F_1) * CON(F_2)$$

Therefore, by considering the above factors of the continuity safeguarding subsystem, the general operating level of the continuity safeguarding subsystem is represented in the following equation:

Equation 12 General operating level of continuity safeguarding subsystem CON

$$CON = (SUP + CON(Q) + CON(F) * CON(T))/3 * CON(C)/100$$

4.2 Model determinants with a case study

4.2.1 Case description

Jinshan Hospital is a center for infectious-disease control, located in Shanghai. The general characteristics of the hospital are illustrated in its efficient hospital plan and controlled internal logistics.

Efficient hospital building plan

Promote staff efficiency by minimizing distance of necessary travel between frequently used spaces. Allow easy visual supervision of patients by limited staff. Include all needed spaces, but no redundant ones. This requires careful pre-design programming. Provide an efficient logistics system, which might include elevators, pneumatic tubes, box conveyors, manual or automated carts, and gravity or pneumatic chutes, for the efficient handling of food and clean supplies and the removal of waste, recyclables, and soiled material. Make efficient use of space by locating support spaces so that they may be shared by adjacent functional areas, and by making prudent use of multi-purpose spaces. Consolidate outpatient functions for more efficient operation—on first floor, if possible—for direct access by outpatients. Group or combine functional areas with similar system requirements. Provide optimal functional adjacencies, such as locating the surgical intensive care unit adjacent to the operating suite. These adjacencies should be based on a detailed functional program which describes the hospital's intended operations from the standpoint of patients, staff, and supplies.

Controlled Circulation

Jinshan hospital is a complex system of interrelated functions requiring constant movement of people and goods. Much of this circulation should be controlled. Outpatients visiting diagnostic and treatment areas should not travel through inpatient functional areas nor encounter severely ill inpatients. Typical outpatient routes should be simple and clearly defined. Visitors should have a simple and direct route to each patient nursing unit without penetrating other functional areas. Separate patients and visitors from industrial/logistical areas or floors. Outflow of trash, recyclables, and soiled materials should be separated from movement of food and clean supplies, and both should be separated from routes of patients and visitors. Transfer of cadavers to and from the morgue should be out of the sight of patients and visitors. The hospital is also equipped with service elevators for deliveries, food and building maintenance service.

4.2.2 Model variables, parameters and functions

According to the observations and semi-structured interviews which were taken on hospital management level participants in Jinshan Hospital, parameters in the system dynamics model are given specific values, which is presented in Table 9. The variables related to measuring facility operating level are standardized with a value from 0 to 100.

Table 9 Parameter with value in the system dynamics model

Parameters	Values derived from case study
SUP(B)	μ =0.1, Lookup: [(0,0)-(26,100)],(1,90.48),(2,81.87),(3,74.08),(4,67.03),(5,60.65),(6,54.88),(7,49.66),(8,44.93),(9,40.66),(10,36.79),(11,33.28),(12,30.12),(13,27.25),(14,24.66),(15,22.31)]
SUP(A)	μ =0.5, Lookup: [(0,0)-(26,100)],(1,67.03),(2,44.93),(3,30.12),(4,20.19),(5,13.53),(6,9.07),(7,6.08),(8,4.76),(9,2.73),(10,1.83),(11,1.23),(12,0.82),(13,0.37),(13,0.55),(15,0.25)]
SUP(E)	μ =0.3, Lookup: [(0,0)-(26,100)],(1,74.08),(2,54.88),(3,40.66),(4,30.12),(5,22.31),(6,16.53),(7,12.25),(8,9.07),(9,6.72),(10,4.98),(11,3.69),(12,2.73),(13,2.02),(14,1.5),(15,1.11)]
SUP(W)	μ =0.2, Lookup: [(0,0)-(26,100)],(1,81.87),(2,67.03),(3,54.88),(4,44.93),(5,36.79),(6,30.12),(7,24.66),(8,20.19),(9,16.52),(10,13.53),(11,11.08),(12,9.07),(13,7.43),(14,6.08),(15,4.98)]
$\propto_1$	30
$\propto_2$	50
CUL	50%
β_1	0.9
β_2	0.8
β_3	1.5
θ_1	0.8

θ_2	0.7

4.3 Model simulation and results

4.3.1 Simulation by different scenarios

By inputting the specific parameter values into the system dynamics model, the changing trend of functional supporting subsystem, medical function subsystem and continuity safeguarding subsystem operating level can be observed respectively through Vensim software simulation. A simulation analysis is a repeat of the primary analysis or meta-analysis, substituting alternative parameters or ranges of values for factors that were unclear. According to the complex causal relationships between variables, the thesis will only focuses on analyzing the variations of most basic independent variables which are also chosen by Jinshan hospital chief managers and emergency management experts. Hence, main basic factors to be studied in this thesis include location impact reliability, design impact reliability, construction management reliability, building structure reliability, architectural element reliability, water supply system reliability and electrical element reliability of functional supporting subsystem; medical gas and equipment supply reliability of medical function subsystem, emergency training and drill effects and hospital continuity organizational culture impact of continuity safeguarding subsystem. To understand the impact of these factors on overall continuity, the thesis will simulate the effects of factors in two scenarios, a current status and a decrease of 20% of factor value, to follow the evolution of system target. The range of 20% was defined according to the most often range used in literature (engineering, biology, mathematics, finance, etc.). The duration of the simulation period is defined generally as 15 days.

①First, the effects of factors of functional supporting subsystem are simulated.

In current case study with location reliability value set as 100, when disaster occurred, overall functionality will be continuously reduced to lowest level in the first 9 days and gradually recovered in the next days. It is obvious that continuity safeguarding actions performs strong in the disaster due to sound hospital location (see Figure 8). On the other hand, when keeping the other factors undisturbed, by reducing the value of location reliability to 80, the general trend of hospital functional level (see Figure 9) is in accordance with the Figure 8, however, the recover point stays at the 10th day, later than that in the scenario of 100% of location reliability.

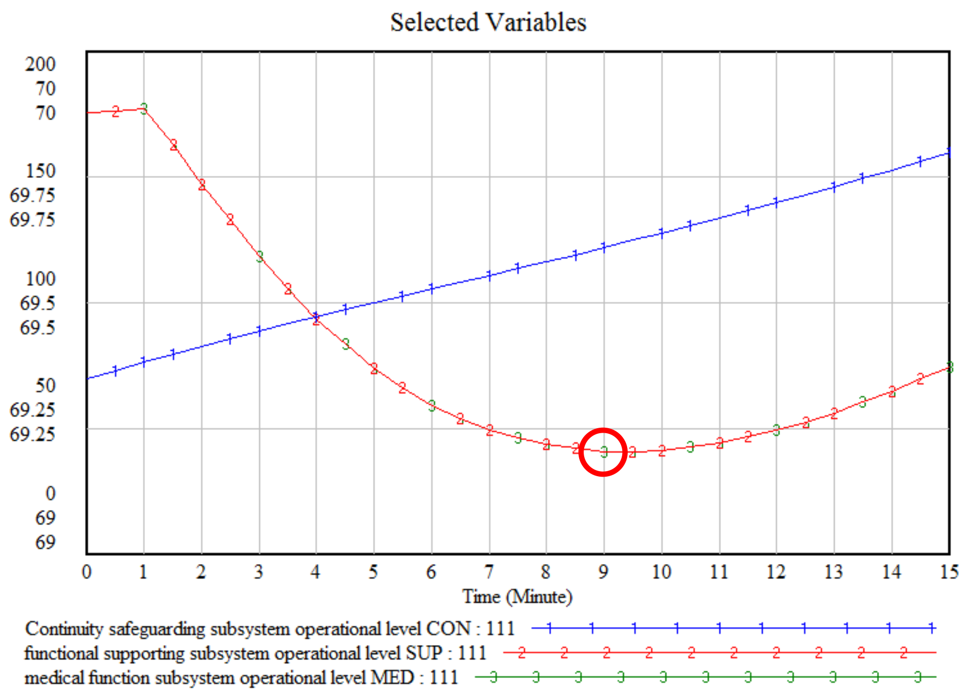


Figure 8 SUP, MED, CON operational level (location reliability=100)

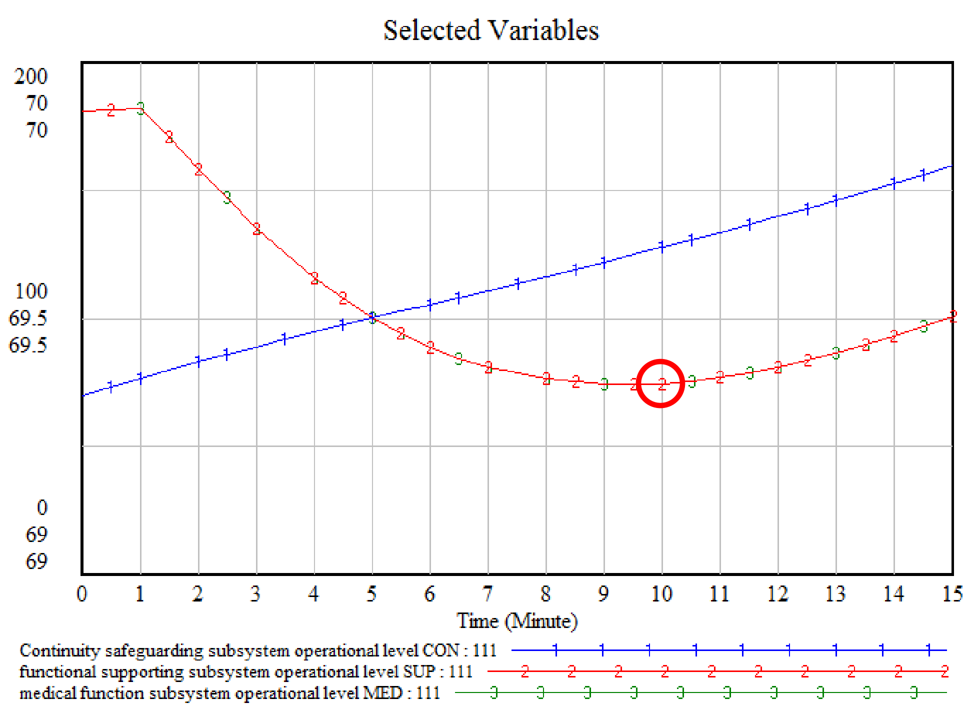


Figure 9 SUP, MED, CON operational level (location reliability=80)

In current case study with building structure reliability value set as 100, when disaster occurred, overall functionality will be continuously reduced to lowest level in the first 9 days and gradually recovered in the next days. It is obvious that continuity safeguarding actions performs strong in the disaster due to sound hospital location (see Figure 10). On the other hand, when keeping the other factors undisturbed, by reducing the value of building structure reliability to 80, the general trend of hospital functional level (see Figure 11) is in accordance with the Figure 10, however, the recover point stays at the 12th day, much later than that in the scenario of 100% of location reliability, that is, this scenario is much worse than that from reducing 20% of location reliability. Hence, it is mandatory to put emphasis on building structures soundness in order to recover the hospital continuity as earlier as possible.

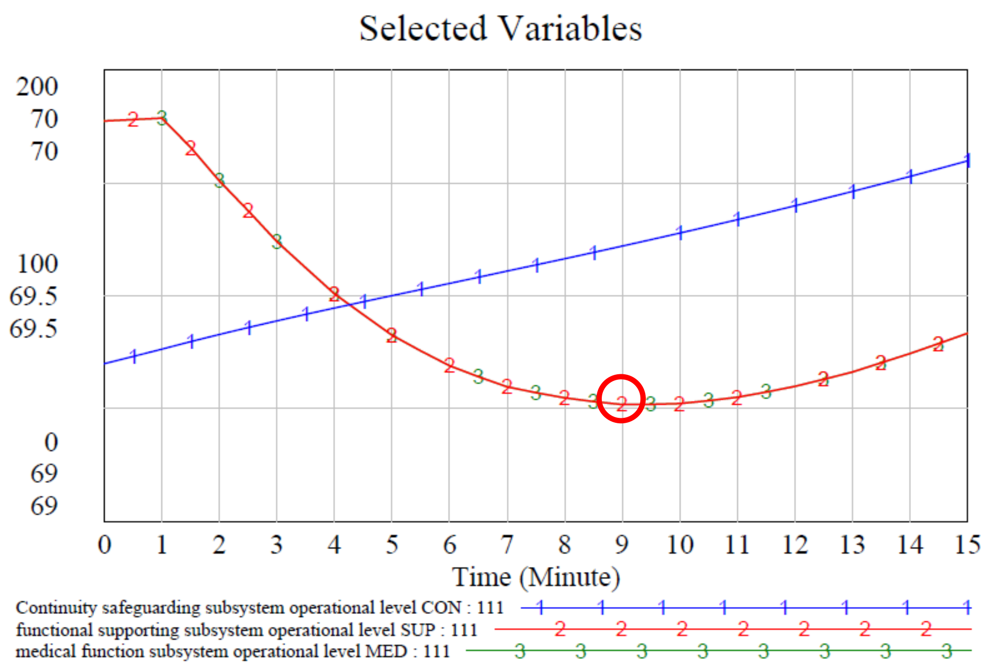


Figure 10 SUP, MED, CON changing trend (building structure reliability=100)

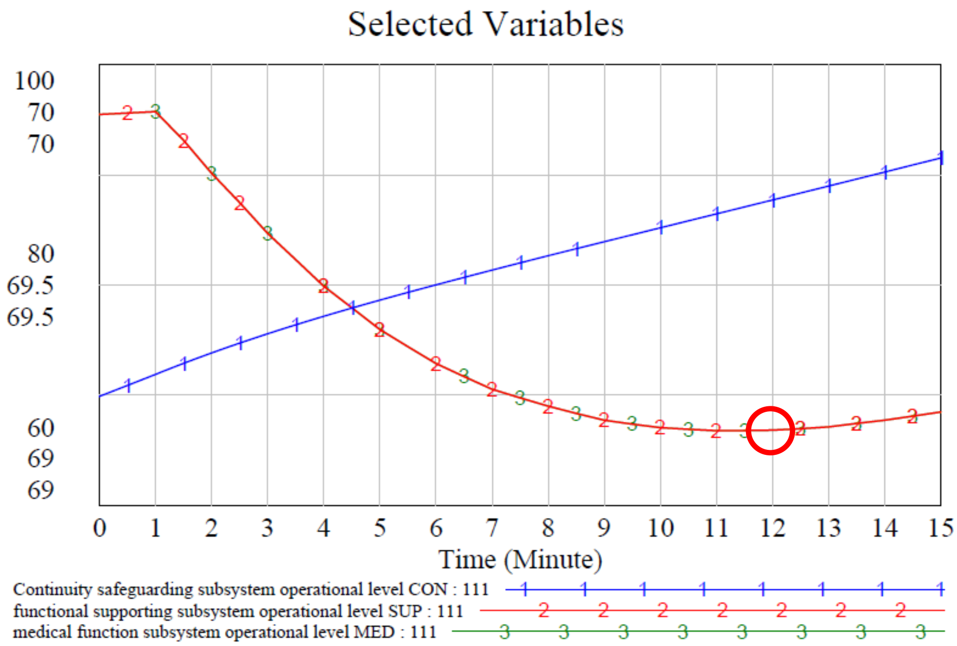


Figure 11 SUP, MED, CON operational level (building structure reliability=80)

Likewise, do the same simulation by comparing the changing scenarios of the other factors and the comparative result of continuity recovery points is shown in Table 11.

Table 10 Comparative result of continuity recovery points

Factors in functional supporting subsystem	Recovery point of current case scenario	Recovery point of 20% decrease of factor's value
location impact reliability	9th day	10th day
building structure reliability	9th day	12th day
construction management reliability	9th day	10th day
design impact reliability	9th day	11th day
architectural element reliability	9th day	12th day
water supply system reliability	9th day	12th day
electrical element reliability	9th day	12th day

②Secondly, the effects of factors of medical function subsystem are simulated.

In current case study with medical gas and equipment supply reliability value set as 100, when disaster occurred, overall functionality will be continuously reduced to lowest level in the first 9 days and gradually recovered in the next days. It is obvious that continuity safeguarding actions performs strong in the disaster due to sound hospital location (see

Figure 12). On the other hand, when keeping the other factors undisturbed, by reducing the value of medical gas and equipment supply reliability to 80, the general trend of hospital functional level (see Figure 13) is in accordance with the Figure 12, however, the recover point stays at the 11th day.

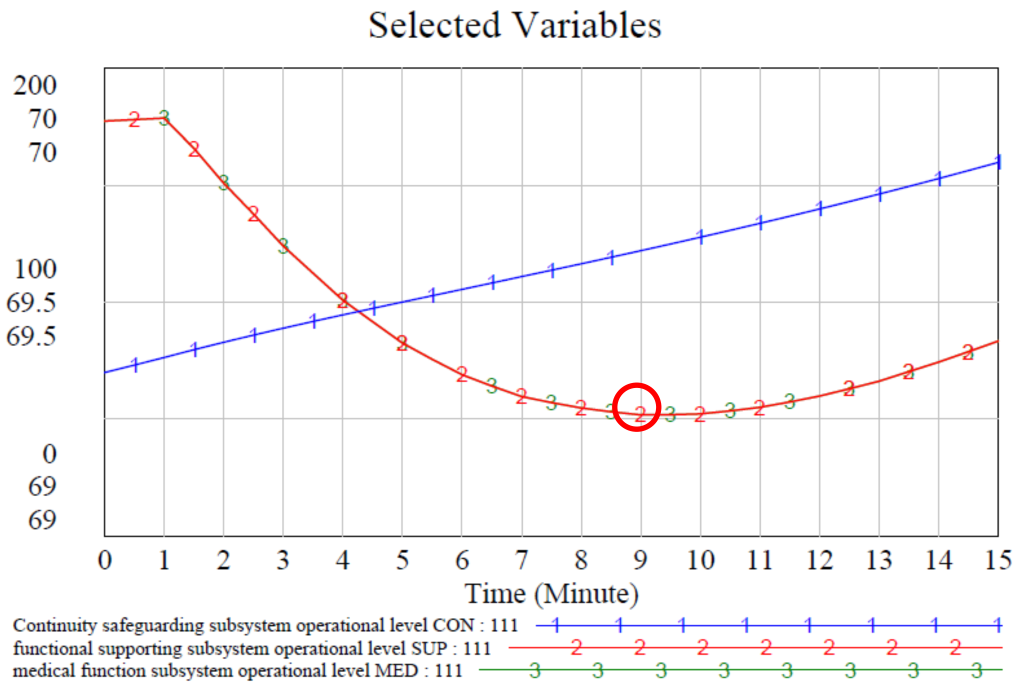


Figure 12 SUP, MED, CON changing trend (MEDe2=100)

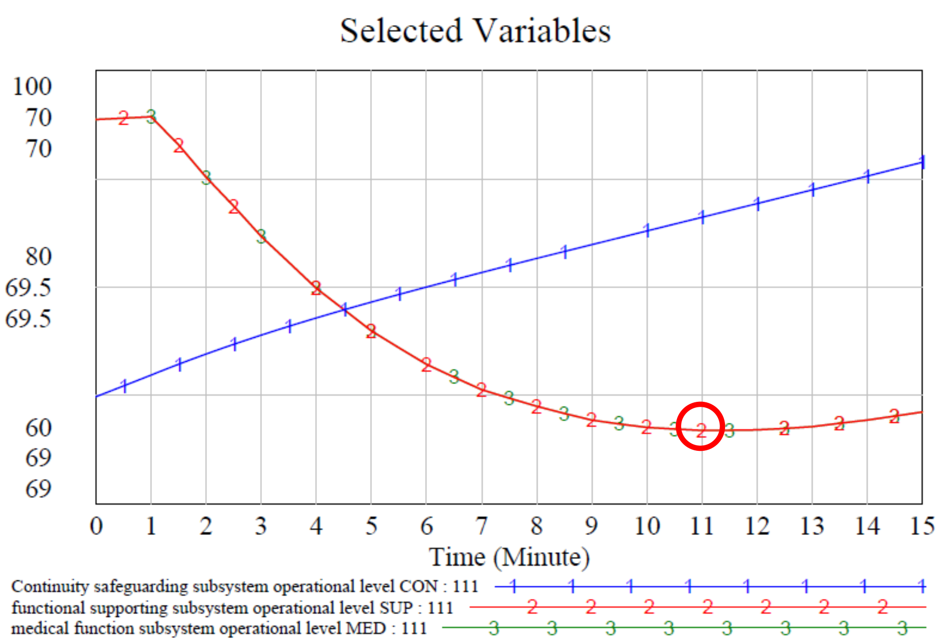


Figure 13 SUP, MED, CON operational level (MEDe2=80)

③Thirdly, the effects of factors of continuity safeguarding subsystem are simulated.

In current case study with hospital continuity organizational culture impact set as 0.5, when disaster occurred, overall functionality change in accordance with the general scenarios. It is obvious that continuity safeguarding actions performs moderate in the disaster (see Figure 14). On the other hand, when keeping the other factors undisturbed, by reducing the value of continuity organizational culture impact to 0.4, the recover point stays at the 11th day, and the continuity safeguarding operational level increases much slower than the former scenario (see Figure 15). The scenarios derived from decreasing the other factors proved similar with continuity organizational culture impact. Hence, Jinshan Hospital should devote more effort into cultivating business continuity management culture to enhance the facility resilience and quick emergency response. The organizational culture proves to be a prerequisite for smooth and effective execution of emergency training and drills.

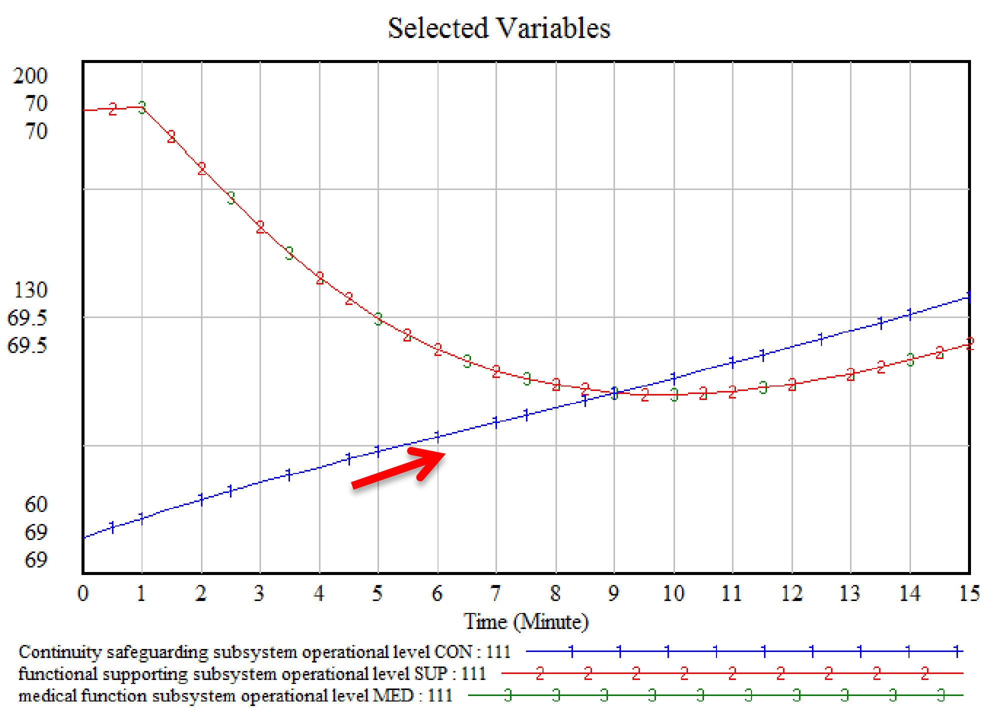


Figure 14 SUP, MED, CON operational level (CUL=0.5)

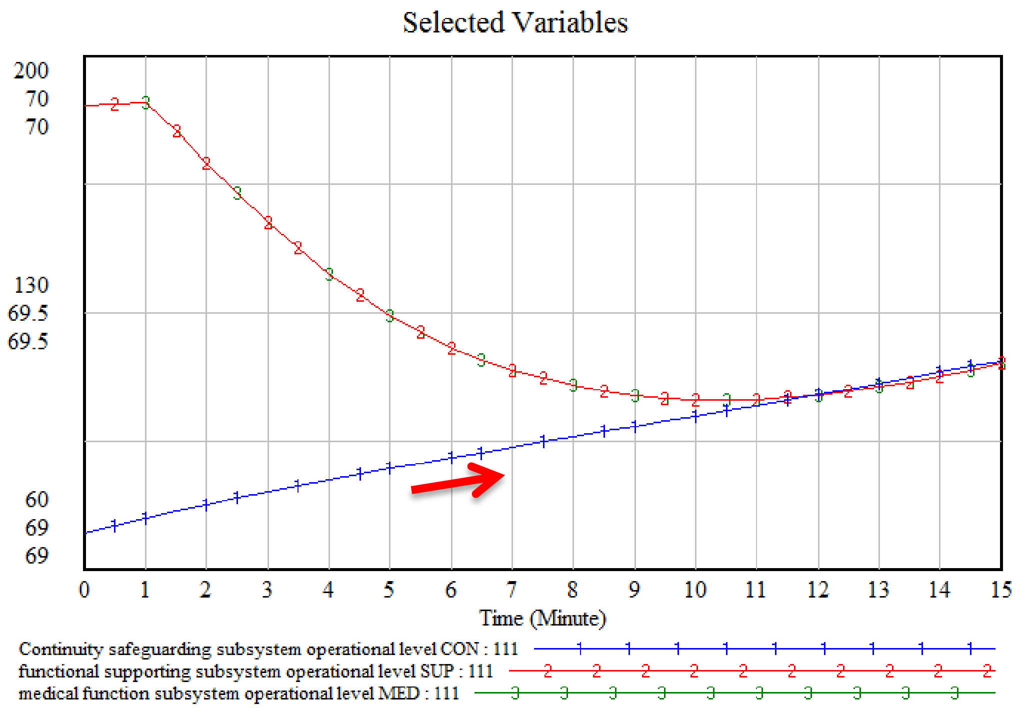


Figure 15 SUP, MED, CON operational level (CUL=0.4)

4.3.2 Model reliability testing

Model reliability refers to the trustworthiness of data and corresponds to internal validity in qualitative research. The thesis adopts semi structured interviews and observation to gather values for variables and parameters in the system dynamic model, which are commonly used for data collection and verified as credible. Specifically, system dynamic model reliability testing aims to validate the realistic growing tendency is identical with the simulation results. It is proved that this dynamic model is reliable because it suits the historical changing trend of operating levels, that is, hospital functionality will be impacted in a certain period and restored thanks to the continuity safeguarding factors.

Besides, there is a need to verify the stability of system dynamic model. The thesis tried various simulation step (DT=1, DT=0.5, DT=0.25) to observe the simulating results of each run. Because each run remains alike to each other and the simulation curve fit each time, it is demonstrated that this system dynamic model is stable and reliable.

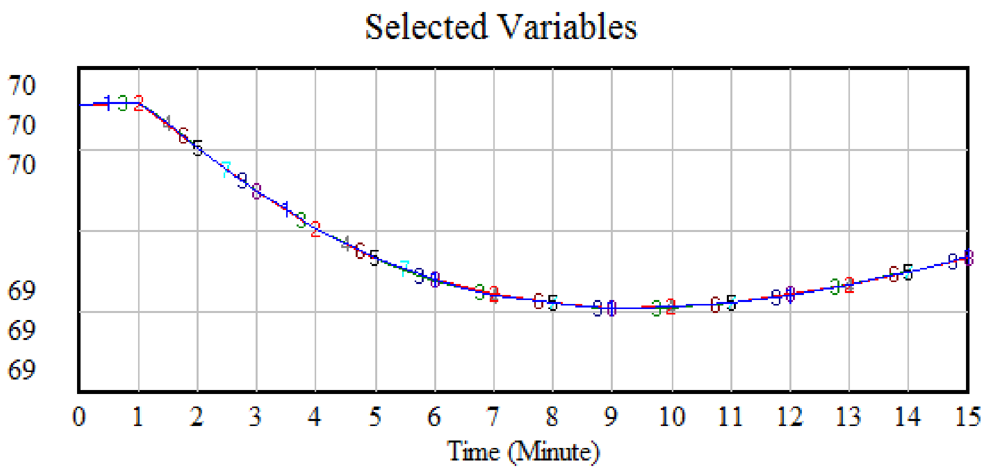


Figure 16 Model reliability testing with different runs

4.4 Business continuity management framework for hospitals

4.4.1 Critical continuity factors and suggested approaches

Based on the comparative analysis between current and 20% value change scenario, critical functionality factors are identified to recover continuity in the earliest manner, including building structure reliability, architectural element reliability, water supply system reliability, electrical element reliability and hospital continuity organizational culture impact. Pre-event disaster mitigation, disaster response and recovery should all cover these factors which have the most significant beneficial effect on the functionality of hospital facility and service continuity.

Regarding hospital physical facility, it is anticipated that there will quite a variation in the disaster performance of hospital building every year. Hospital buildings that are not conforming to rigid design code may be susceptible to collapse or extensive structural damage. A basic approach is to design hospital structure which can withstand the maximum probable disaster impact without significant structural damage. For instance, the seismic loading for new built hospitals are required to be approximately two times the loading of similar non-disaster buildings. Non-structural components such as ceilings, windows, doors, external claddings are the orphans of hospital building facility, which also need extra design attention. A holistic approach to guarantee hospital facility robustness is to conduct facility vulnerability assessment regularly. As illustrated above, hospital safety index provides a snapshot of hospital facility operations based on structural, non-structural and functional factors, including the environment and health service network to which it belongs. By determining the vulnerability or risk of hospital daily operations, decision makers can have an overall idea of its ability to respond to disasters and potential hazards. Furthermore, hospital is able to determine possible targeted strategies to overcome or reduce the vulnerabilities.

Disaster preparedness plan is crucial to quick disaster response such as evacuation. Enhancing the quality of disaster management training to establish a risk mitigation and business continuity culture is a prerequisite for successful disaster plan operation. Inappropriate hospital evacuation may involve substantial risk to patients and could inappropriately result in the removal of the hospital as an immediate and valuable health care resource for community. There is a need to define evacuation conditions comprehensively in a common framework (e.g. evacuation, temporary evacuation, collapse and partial collapse) to insure an accurate and uniform description of hospital status, to avoid chaos when disaster occurs. Hospital staff should be trained how to react when they are unable to access damaged hospital facilities or deal with various circumstances. They should also be trained to improve leadership capacity to facility disaster response and management. This will achieve by the need to improve the capacity to learn, recognize the responsibility to share lessons learnt and establish hospital business continuity culture.

Resourcefulness, with regards to emergency water and electricity backups as well as enough medical gas and equipment, is the availability of resource before, during and post disaster that are necessary to sustain hospital services. According to the factor causal relationships in the system dynamic model, resourcefulness will be reduced by three key resources for disaster management: staff shortage, the decline in hospital stock of medical supplies and disruption of utility services such as water, power and sewage services. It is demonstrated that hospitals have high dependence on local support agency for disaster response. Generally, subject to most disaster damage to transportation, emergency supplies can be made available with the assistance of supporting agencies such as helicopters delivering supplies to isolated facility. However, the thesis highlights the need for hospitals to stock up or plan their own medical and food supplies in advance if the risk of disaster is high. Also hospital stock resourcefulness can be enhanced by the redundancies in the hospital system and community. For instance, the backup hospital supplies, extra fuel for power generation and support from external agencies.

Therefore, these critical functionality continuity factors and suggested approaches comprise a hardcore of hospital disaster preparedness for robust continuity.

4.4.2 Business continuity management framework

Hospital business continuity framework is constituted by critical functionality continuity factors and sequential planning processes. As discussed in literature review, business continuity framework includes pre-event, during-event and post-event stages. By incorporating critical continuity factors into the three stages, a comprehensive business continuity management framework for hospitals can be formed (see Figure 17).

In the pre-event planning process, the main task is to conduct hospital facility risk management and business impact analysis so that hospital built infrastructure vulnerabilities can be fully investigated and managed in advance. The facility management department and disaster management department should collaborate to assess each facility and develop maintenance plan. Disaster plan is based on a synthesized knowledge by facility vulnerability evaluation and disaster impact analysis.

During-event process deals with implementation of disaster management plan. The success of performing quick disaster response is determined by disaster drills or training exercises. Coordination between different agencies during response is particularly crucial.

Post-event process involved recovery of all hospital operations and providing critical feedback from hospital staff in order to capture new insights across hospitals.

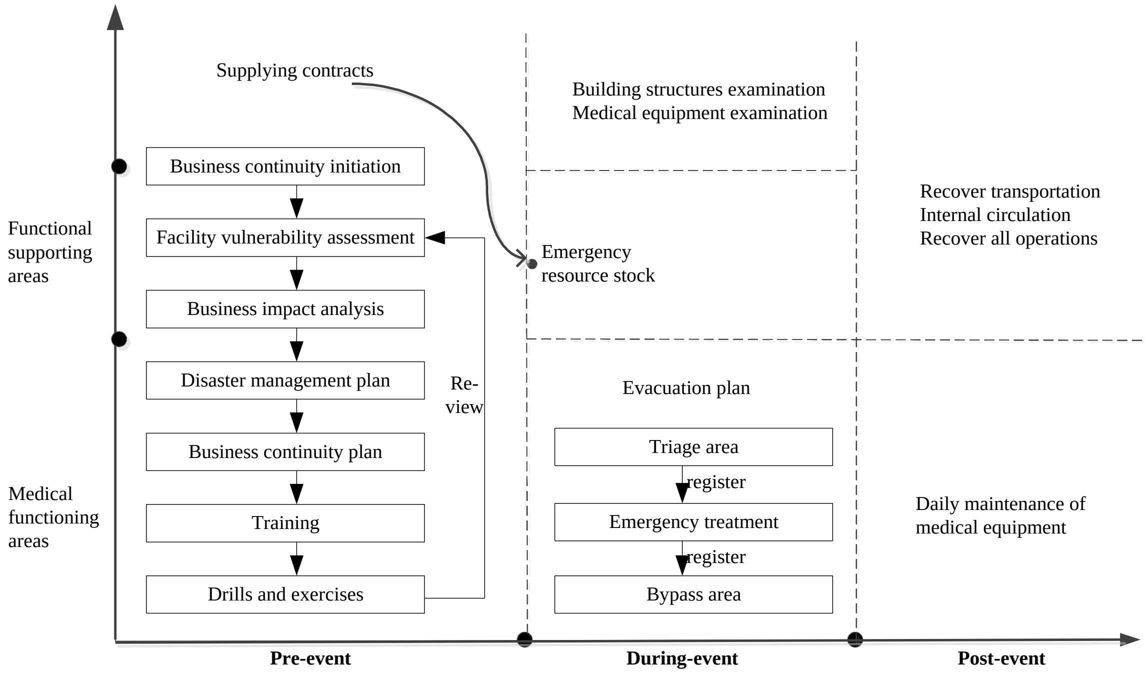


Figure 17 Business continuity management framework for hospitals

CHAPTER 5: DISCUSSION

The hospital functional continuity system developed in the thesis has implications for both disaster and facility management as discussed through all chapters.

The thesis outcomes a staged business continuity framework for disaster management which can be incorporated into policies and disaster planning governance structures at regional and local level. The findings will instigate disaster management to develop appropriate strategies and polices by recognizing the diversity and interdependencies between hospital functional continuity factors. The findings also contribute to the hospital managers understanding of broader vulnerabilities and complexities that can hinder hospital service delivery during disasters. For instance, better understanding of potential risks allows more informed disaster impact to deal with damages. This emphasizes the need to invest effort in enhancing hospital staff capability and leadership through appropriate training and regular disaster planning drills.

An integrative approach to hospital facility management and disaster planning is also significant. The description of facility management and disaster management constraints in hospitals recognizes the need to integrate building facility assessment into disaster preparedness process. The findings suggest greater compliance with hospital design code, so that disaster planning agencies will not overlook hospital development by incorporating more vigorous measures to ensure facility robustness.

The thesis provides new insights to improve the hospital disaster management planning process and enhance service delivery capacity to hazards. Theoretically, the business continuity framework provides an ideal framework to improve hospital adaptation. Yet, the findings raise questions that need to be future investigated. For instance, it is necessary to do cost-benefit analysis before making disaster preparedness plan. More information should be gathered to justify the interdependencies between hospital functional continuity factors, especially with regards to causal relationships between facility and medical services.

CHAPTER 6: CONCLUSION

The built environment is a critical asset to maximize community resilience to deal with disasters, and hospital is particularly a crucial entity to absorb disaster impacts and maintain its medical services during adversity situations. Based on a comprehensive literature study on facility management, disaster management, business continuity management, the thesis proposes a method to rethink disaster preparedness for hospitals.

By analyzing safe hospital safety index and resilience, hospital functional continuity factors are determined in three dimensions. The thesis describes the use of system dynamic model to present the interdependencies of hospital functional continuity factors which comprises functional supporting subsystem, medical function subsystem and continuity safeguarding subsystem. A key emphasis of the system dynamic modeling is to identify critical functional continuity factors by scenario simulations. To understand the impact of these factors, the thesis simulates the effects of factors in two scenarios, a current hospital case operating status and a decrease of 20% of value of independent factors, to follow the evolution of hospital continuity capacity level. The results demonstrate the urgent need to incorporate hospital facility management and disaster management into a time sequential business continuity framework including pre-event, during-event and post event processes. Hospital facility vulnerability and disaster impact analysis in pre-event stage are pivotal in establishing hospital operational continuity that is resilient to disasters. The framework can be generalized and applied to general hospitals. The limits of this thesis are essentially linked to the robustness of system dynamic model because of the limited time and literature studied to develop the model, to define variables, to create the simulation and to interpret the results. The in-depth of the thesis is also restricted due to case study semi-structured interviews and the participants investigated within the given time frame. Only one hospital is selected to gather interview data which may ignore the integrity of interviewee network. The qualitative findings of the thesis need further justification to produce a rich description of hospital functionality continuity and a generalized hospital business continuity framework.

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