Retrofit Strategies For Hospitals in the Eastern United States

by George C. Lee, Mai Tong and Yasuhide Okuyama

Research Objectives

This paper describes an approach used to develop retrofit strategies for hospitals and other critical facilities in low to moderate seismic hazard zones, where strong earthquakes are infrequent, but if they should occur, the consequences would be high. Hospitals in New York State and other urban centers in the eastern U.S. fall into this category, where seismic retrofit requires information on the impact of losing medical services after a destructive earthquake. A team of MCEER researchers is currently developing an approach to address this task. It is a truly multidisciplinary effort, with team members from a variety of disciplines including engineering, seismology, structural dynamics, risk and reliability analysis, manufacturing process engineering, computer simulation, urban and regional planning, and economics. When this research task is completed, it will be united with MCEER's general hospital project to develop seismic retrofit strategies.

A major MCEER research thrust is the development of retrofit strategies for critical facilities. By fostering team efforts, the research is focused on comprehensive protection of emergency medical service function of hospitals in the event of a destructive earthquake. This research requires system integrated studies involving earthquake hazards, fragilities of all structural and nonstructural components and systems, as well as human services provided by medical and support staff, and impact and benefit-cost analyses. Experiences and approaches developed from the hospital projects will then be extended to seismic retrofit of other critical facilities such as communication centers or manufacturing complexes.

MCEER's hospital retrofit research program addresses two specific types of seismic hazard locations. The first is for hospitals located in regions with frequent and/or high seismic hazard levels such as many communities in California where retrofit is required by law. The second type of hospitals are those located in regions with low seismic hazard levels where earthquakes have a very long return period but the structures and contents are likely to be damaged when earthquakes do occur.

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For the first type of hospitals (e.g., those in California) a considerable amount of engineering and social science studies are being carried out by MCEER and other researchers (for example, see Johnson et al., 1999). Relatively little information is available on how to approach hospitals located in low seismic hazard regions but having high risks (e.g., those located in eastern U.S. urban centers). This article briefly summarizes MCEER's approach in developing retrofit strategies for the latter, with an emphasis on establishing an evaluation system for retrofit strategies.

Different Questions Asked for California and New York Hospitals

Because of California Law SB1953 (Alquist Act), California hospital administrators and code writing authorities are required to consider the nature of functional design for critical care facilities. OSHPD (California Office of Statewide Health Planning and Development), which is directed by SB1953 to address and implement the legal requirements, now requires that by January 1, 2030, all hospital buildings will meet the seismic standards of the Hospital Act. Also, OSHPD is in the stage of writing the implementation procedures required by SB1953 for the nonstructural provisions. Under such legal requirements, the challenges for California are largely focused on engineering tasks.

In areas of the eastern U.S. such as New York City, hospital retrofit decisions are made based on different considerations. In particular, given that only limited financial resources are available for protection from various natural hazards of approximately the same level of probability of occurrence, retrofit decisions become an optimal risk management issue. For these two different conditions, we may thus begin by asking two different questions for the MCEER hospital project.

For California hospitals:

- How can the requirements to retrofit be met cost-effectively?

For New York hospitals:

- Should resources be allocated for the seismic retrofit of hospitals?

MCEER's hospital project is divided into two separate aspects in their initial phase. For the more general situation (represented by California hospitals), major efforts are devoted to engineering activities to establish fragility information for the physical components and systems, and identify critical problem areas in structures, nonstructural

Hospital administrators, building owners and other stakeholders in regions of minor to moderate seismicity can use the evaluation system for retrofit strategies to make optimal risk management decisions. Resources for hazard mitigation of all types are limited, and a decision-making method based on solid cost-benefit principles will be a valuable tool.

components, equipment, etc. that require seismic retrofit. For the second situation (represented by hospitals in the eastern U.S.), we concentrate on establishing a decision-making method which can provide information on the impact to the community if medical service function is lost after an earthquake due to different levels of damage scenarios to the various required service functions of the hospital. Once a decision is made to perform seismic retrofit, the process will be merged with that developed for the California hospitals. At that point, we consider impact to the community when there are multiple hospitals, followed by benefit-cost analyses for different possible retrofit options.

System Evaluation for Hospitals in New York

We envision a five-step decision-making process for the seismic retrofit of hospitals. These steps are:

1. Establish earthquake hazard
2. Develop fragility information and identify critical problem areas in the physical system
3. Establish an analysis tool (hospital operation model) to carry out evaluation of selected seismic scenarios to determine their impacts to medical services of a given hospital
4. Carry out community impact analyses (multiple hospitals/health care facilities)
5. Perform benefit-cost analysis and determine retrofit options.

For a free-will decision, the third step is crucial because the retrofit benefit has to be evaluated in comparison to those of other competing projects for limited resources.

Being aware of this important link, MCEER is concentrating on the third step by working with several hospitals in New York State. These hospitals are located in Seismic Zone C (Z = 0.15), where earthquakes with magnitude ≥4.5 or intensity ≥VI have been experienced historically.

For the purpose of evaluating various natural hazard reduction schemes, we start to develop a hospital operation model based on patient flow as shown in Figure 1.

If hospital services are considered as a process, the key element in this patient-flow model is the center block that describes the process of how patients receive their medical services. The services are supported by two types of resources: human

Links to Current Research

Program 2: Seismic Retrofit of Hospitals

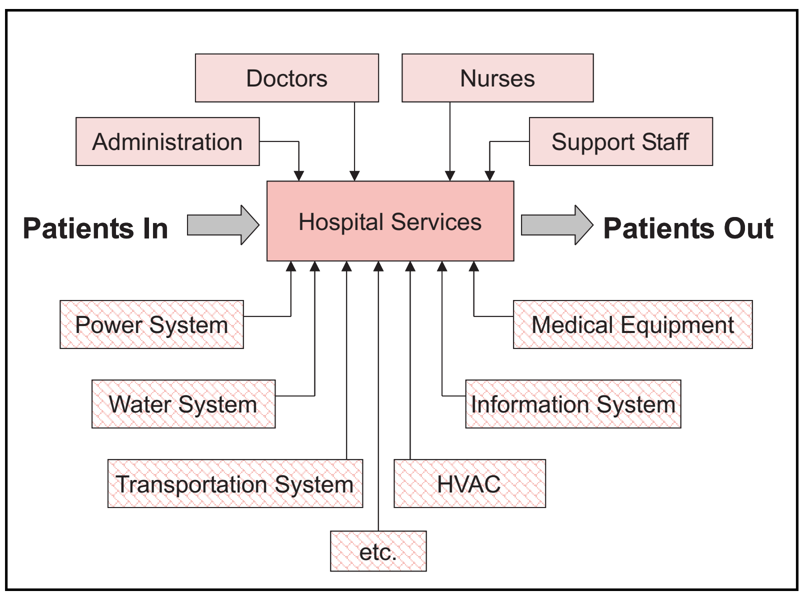


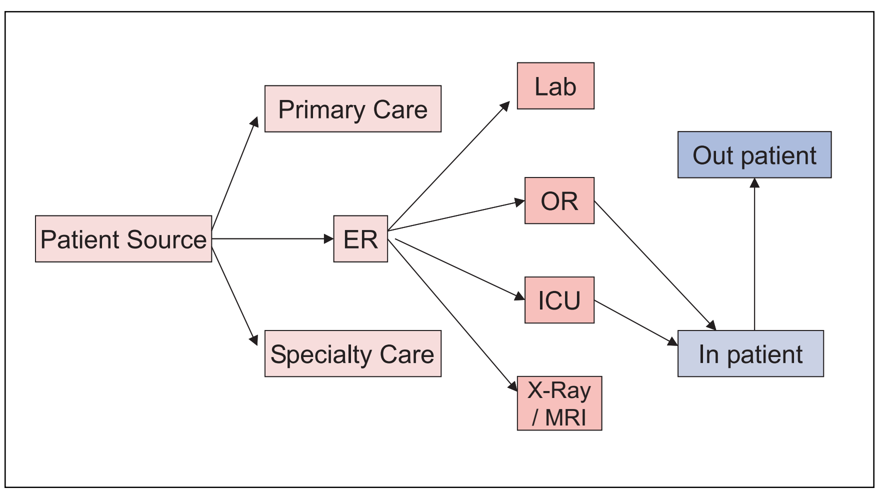
Figure 1. The Patient Flow Model of a Hospital

and material. Since our target is to evaluate the benefits of structural/nonstructural retrofit, the emphasis is given to material resources, which typically include power systems, water systems, information systems, medical systems, transportation systems, HVAC and others. Depending on the designated function of hospitals (trauma center, general hospitals, special medical care, etc.), the center block will involve different service units. Our current emphasis is on modeling the emergency medical service, which is illustrated in Figure 2.

Each of the service units has internal structures and are interconnected. Therefore, modeling of the hospital operation has to consider two layers of relationships.

With the emergency medical service unit of a hospital configuration described in Figure 2, a key step of modeling is the internal relationship between various service units (departments) and the delivery of emergency medical services. In particular, some factors such as seasonality, abnormality, and patient distribution, a critical disaster event may have a different impact to these relationships. Also, to evaluate different retrofit schemes, the level of detail of the model may vary. In Figure 2, only some typical service units are indicated for the purpose of illustration. The arrows only provide examples of possible one direction patient flow. The total system would be too complicated for illustration of the concept. In general, an all-purpose comprehensive model may not be a good approach, since too many factors introduce too many uncertainties, which would eventually lead to an unreliable model.

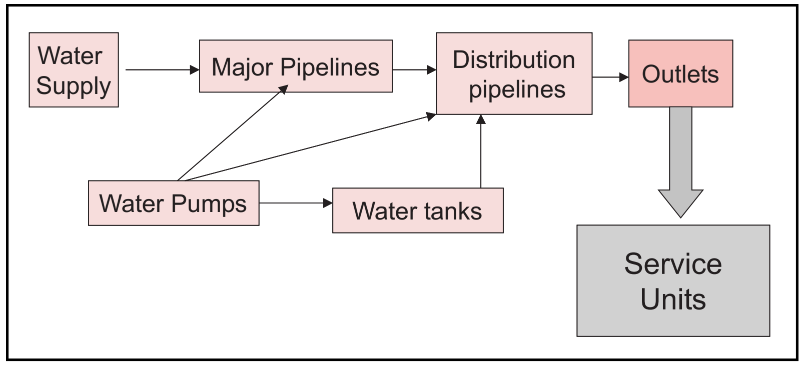
Similar to modeling the necessary components of providing emergency medicine, the utility system such as water supply, as expressed in Figure 3, can be modeled so that the relationship among the various units can be examined (e.g., effect of damaged water pumps on the water supply). This utility model can be linked to the emergency medical service model, where consumption of water is required. Here,



■ Figure 2. Hospital Medical Service Units it is important to understand that the same utility system may be modeled differently for application to various physical problems and retrofit treatments.

Forrester Network Model

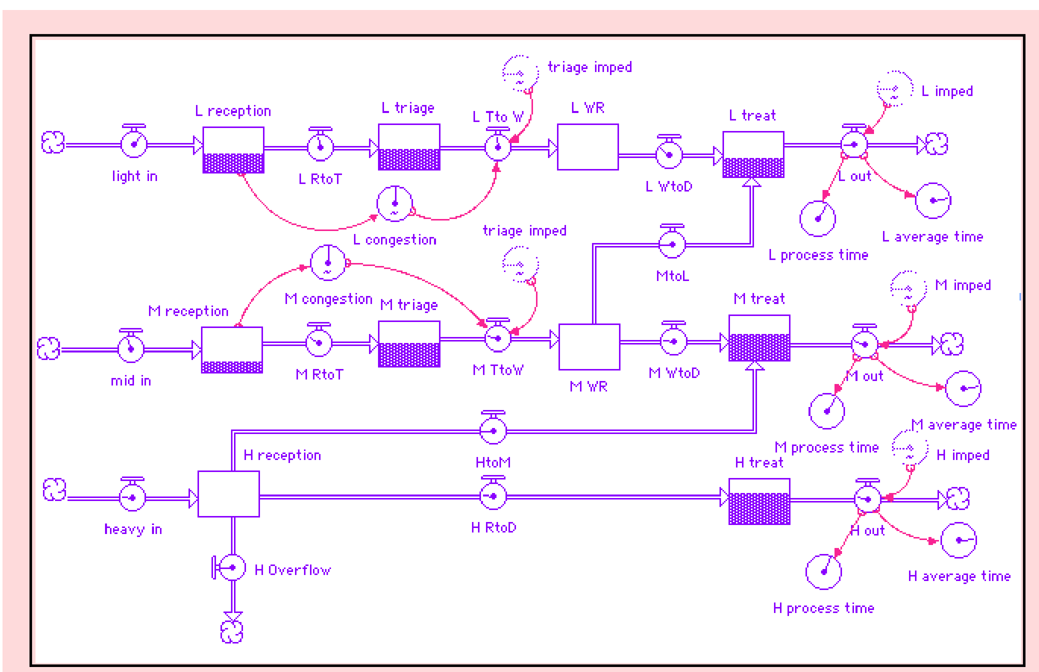
As mentioned earlier, the purpose of modeling hospital operation is to evaluate the benefit of seismic retrofit. For this reason, we need a quantitative model. This requirement can be satisfied by a Forrester type of network model. The essential steps of a Forrester model are to break down the physical units and their relations into standard input/output units and networked relations between these basic units. Then the relations are modeled by difference functions including differentiation, integration, and other elementary



■ Figure 3. Water System Units

functions; or they could be represented by an empirical function or some logical relations.

Figure 4 shows an example of Forrester-type systems model for the emergency room in a large hospital. Incoming patients are classified into three categories: minor, moderate and major injuries/illness. Patients classified as minor and moderate are attended to first, and complete an information sheet in



■ Figure 4. Forrester Type Systems Model for Emergency Room Operation the reception area; they then proceed to the triage rooms for treatment. The time spent in this process (reception to triage) depends on the degree of injuries/illness (patients classified as "moderate" spend more time than those classified as "minor") and on the capacity of the triage rooms. Then, after the triage room, the patients proceed to the waiting room before receiving treatment. The time spent in this process (waiting room to treatment room) also depends on the degree of injuries/illness and the capacity of treatment rooms for minor and moderately injured patients. On the other hand, a severely injured patient skips the triage process, due to the urgency of their injuries/illness, and the information on their injuries is provided by paramedic staff. The time spent from reception to treatment for a patient classified as "major" depends on the capacity of the treatment rooms. Because this model represents only the operation of an emergency room, the patients are moved out of the model after the treatment rooms.

Once an internal disaster occurs (such as fire, water pipe broken, power outage, and so forth), the process times of the triage room and treatment room are affected and become longer depending on the damage. In order to simulate an internal disaster, the material resources of the hospital are modeled as shown in Figure 5. Internal disaster in this model can be damage to either water pipes, electric lines, medical gas pipes, emergency room structure, structure in the other areas, medical supplies in the emergency room, the inventory of medical supplies in the hospital, or any combination of these situations. The damage can be defined as a time variant function (either continuous or discrete). In general, lifeline facilities, medical gas, and medical supplies are modeled such that under normal circumstances, these resources are consumed on a per patient basis, and the inventory is filled either when consumed (water, electricity, medical gas) or when additional supplies are purchased (medical supplies). Once an internal disaster occurs, one or more of these resources sustain damage. For water, electricity, and medical gas, the piping may be damaged and they cannot be supplied as usual (reduced amount or total cut off). Then, emergency transfer from the reserve tanks (for water and medical gas) or from the hospital power generators (for electricity) compensates for the reduced supply. The capacity of these reserve emergency measures can be specified by resource. For medical supplies, when an internal disaster limits their capacity in the emergency room or damages them directly, reserve supplies can be transferred from the hospital's inventory. In conjunction with damage to lifelines and supplies, related laboratories (such as X-ray, blood test, and so on) and facilities (operating rooms, intensive care units, and so forth) in the hospital are also restricted by the internal disaster.

The impacts on these material resources are then fed back to the operation model discussed above. Due to the internal disaster and related damage, the process times of both triage and treatment rooms are affected, and become longer. Consequently, the number of patients treated in this emergency room may be reduced in a complex manner. The degree of impact to each patient (classified as minor,

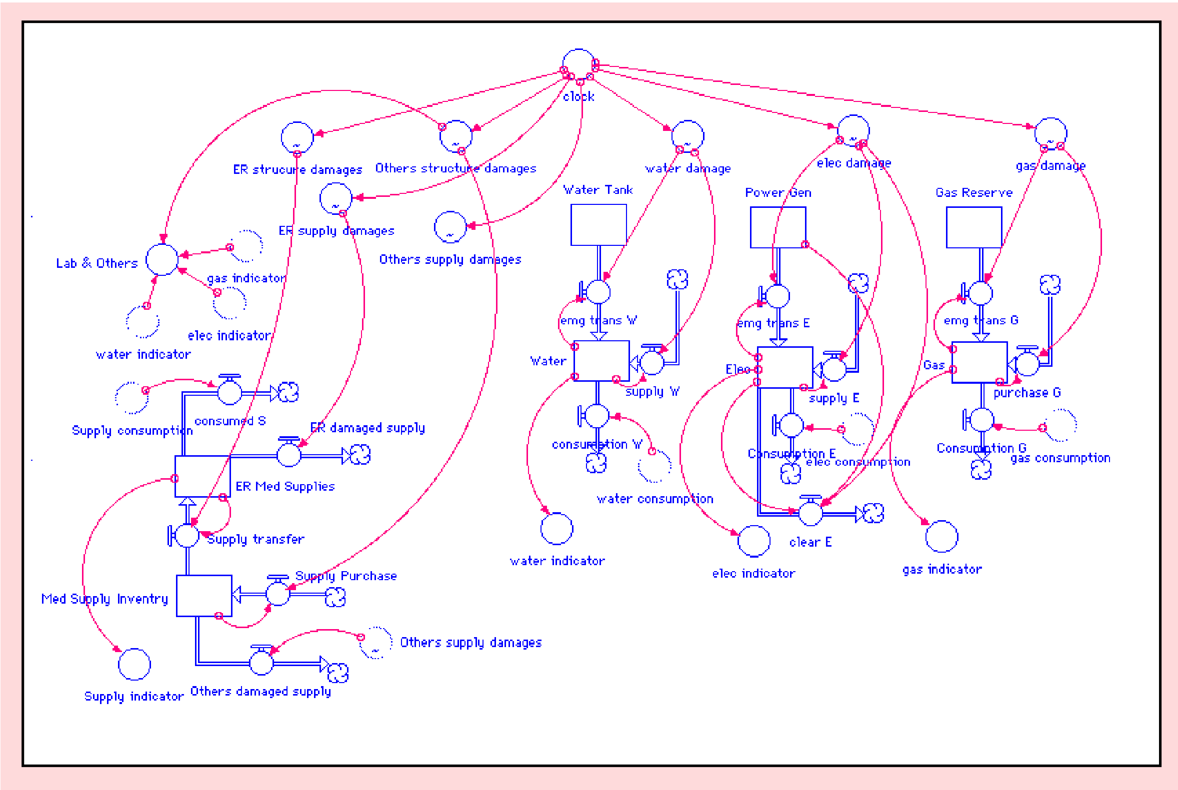


Figure 5. Sub-Model of Material Resources for Internal Disaster

moderate or major) may vary due to the different requirements for treatment (for example, a patient with major injuries requires more electricity, medical gas, and medical supplies than less seriously classified patients).

This model can be tailored for a specific hospital with information regarding the capacity of the emergency room and hospital, and the size of its emergency reserve of resources. The model can simulate patient flows through the emergency room under any scenario of internal disaster, external disaster, or a combination of both. The model can also provide statistics, such as average treatment time, average time spent in the waiting room, and so forth.

Transfer Function and State-Space Models

A Forrester type of network model is convenient for modelers, but it is not easy to carry out system analysis and evaluation. Fortunately, we have several other analytical models which are equivalent to the time domain network model. Two of the most useful equivalent models are the transfer function model and state-space model. For these models, many available control theoretical analyses can be applied. For instance, the zero-pole analysis for transfer function analysis may help us to understand the frequency domain characteristics of the modeled system. Several impact response parameters such as arising time, adjusting time, peak response time and PO% (percentage overshoot) may provide a quantitative measure of the hospital performance under a sudden hazard event.

For instance, consider an earthquake event which results in a sudden increase of in-flow patient rate and simultaneous damage to some utility systems. With the shortage of medical staff, water and power supply, the medical services of the hospital will be reduced while patients are arriving at a much higher rate. The rising time indicates how quickly the hospital capacity will be saturated. Adjusting time reveals how long the services delay problem will last. The peak response time indicates when the worst case will be and PO% describes how bad the situation could be. With these evaluations, we may be able to determine how much service loss will be from the event. Consequently, the value of a retrofit will be evaluated against the chance of the risk and the associated potential loss.

Conclusion

Based on information supplied to us from the hospitals in New York, we are in the process of establishing these models. It is our intention to examine the dynamic behavior of the emergency medicine unit of the hospitals under prescribed hazard conditions and damage scenarios, and eventually to develop a cost vs. risk evaluation procedure leading to decision-making support for seismic retrofit.

Some pertinent references concerning retrofit strategies for hospitals are provided.

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