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A Framework to Evaluate the Resilience of Hospital Networks

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Abstract

This paper puts forward as framework to evaluate the resilience of hospital networks. Natural and man-made disasters can lead to significant social, economic and socioeconomic losses. Enhancing the resilience of communities in face of disasters can reduce these losses. Resilience is the ability of a system to resist, absorb and eliminate the effects of a hazard and to resume its performance at the desired level at an acceptable time. The resilience of hospital network in a community is among the most critical factors in reducing the losses caused by disasters. However, in many situations, the failure of one or multiple hospitals in a network reduces the overall capacity of the network, forces the movement of patients from one hospital to another, and leads to significant losses. There is need for an appropriate index that can be utilized in order to evaluate and measure the resilience of hospital network and identify the opportunities for enhancing its resilience. In this paper, a hospital network resilience index is presented. A simulation framework is also introduced in order to measure the resilience of hospital network under uncertainties about the magnitude and consequence of hazard, response of various components of hospitals, and the performance of transportation network and lifelines such as electricity network. The proposed framework can be utilized in order to evaluate the impact of lack of hospital network resilience on its capacity to treat the casualties of a disaster, the movement of patients from one hospital to another as a result of inability of a hospital to provide services, and the subsequent losses.

Keywords: hospital network; resilience index; simulation; uncertainty.

1. Introduction

Natural and human disasters have always existed and caused a lot of damage. Among the most devastating disasters are earthquakes. Earthquakes often damage vulnerable infrastructures and cause casualties in most regions frequently. For example, the 2010 M7.0 Haiti Earthquake left more than Two hundred thirty thousand people dead [6].

Measures can be taken to reduce these injuries and losses, including providing proper medical services after an accident [5]. Hospitals play a critical role as they treat the earthquake casualties and prevent the death toll from rising. They are faced with increasing demand after an incident, and on the other hand they must be able to serve the injured people [9]. Hospitals must save their performance in the face of earthquake (i.e., they should not sustain damage or if damaged they should resume their services in an optimal manner) [3]. This is the fundamental characteristics of a resilient hospital. Hospital disaster resilience is the ability of the hospital to respond, resist and absorb the disaster effects to provide health care, and then return to the basic or acceptable level of service [11]. In many cases, when there are multiple hospitals in an earthquake affected region, the patients are moved from hospitals that are damaged or overloaded to the one that is capable of accepting more patients. Therefore, although some hospitals may fail or collapse, the network might be able to handle the surge in the demand.

Hospital network managers and planners need to investigate the impact of an earthquake on the individual hospitals and the network as a whole in order to determine the resilience of healthcare system in a region and plan for mitigation strategies.

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Recent disasters have shown that various areas, such as human resource management, planning, hospital integration, and the establishment of strong and coordinated relationships between different structures, are needed [7]. There are not enough research in hospital network resilience field. Single hospital resilience is studied in [1], [2], [4], [7] and [8] but last research studies focus only on one hospital and there is no indicator for a multi-hospital system review taking into account the interactions of system components. This is while we know that components affect each other in a system. For example, a lack of capacity of a hospital affects the performance of other hospitals and, as a result, reduces overall resilience. Therefore, the robustness of hospital network must be enhanced**.**

The objectives of this project are introduction of an appropriate index to estimate the probability of hospital network resilience, called the Hospital Network Resilience Index (HNRI) and providing a tool for simulating the performance of hospital network after an accident, taking into account uncertainty. Final objective is introducing a suitable model using HNRI to analyze the problem of making decision about hospital location and capacity measurement.

Decision-makers in this field need to first have an index to measure the resilience of the treatment network, and then they can be involved in investing in the construction of a new hospital or increasing the capacity and rehabilitation of the current hospitals with a model. In this project, first, the effect of reducing the capacity of a member of the treatment network on the entire network should be estimated and the capacity of the post-incident treatment network should be determined in general. Then, a solution is given to improve the overall network performance by adding a new unit, or increasing the resilience and capacity of the current units. If a new unit should be built, its position and capacity will also be determined.

2. Research Background

Due to the possibility of disasters and accidents such as earthquakes, it is necessary to take steps to deal with its destructive effects. One of these measures is to increase the resilience of the hospital networks taking into account their interactions in the system. Some studies have been done about this problem. Achour et al. [1] detected the effect of different factors on the level of resilience by using a questionnaire from different hospitals. The six factors that were more effective than the others are indicated by xi in relation 1 as follows:
electricity (x1), gas supply (x2), water supply (x3), landline telecommunication (x4), mobile phone (x5) and Personal Handy-phone System (PHS phone) (x6).

$$y= -1.36x_1 +0.163 x_2 +2.059 x_3 -0.067 x_4 +0.043 x_5 +1.27 x_6 +0.123 \quad (1)$$

Cimellaro et al., [4] first, introduced the function parameter for a hospital. Figure 1 shows the process of its change after the incident. Then, this parameter is formulated using the waiting time for one hospital and using the number of patients in queue for hospital networks.

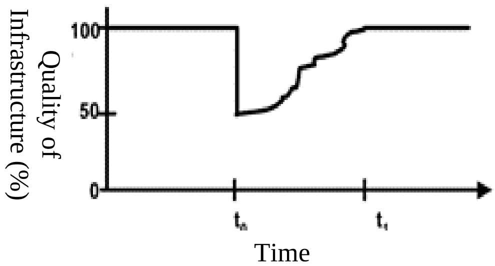

Fig. 1. Changes in the quality of infrastructure performance [4].

Also, Arcidiacono et al. [2] have created a software for calculating the resilience of each section of society. The software is developed using the relationships in their last papers. The inputs of the proposed system are related to the relevant structure information, such as the location and physical parameters of the infrastructure and the failure parameters. Using this system, the resilience of each of the structures is analyzed, and then, their weighted average results in the resilience of that section of society. This review is done regardless of uncertainty.

Another study was done by Cimellaro et al. [4] that functionality is considered to be a function of quantitative and qualitative functionality for the calculation of resilience according to the following relationship. Where T_{lc} is the control time (usually life span of the system) and t_0 is the time to start observing.

$$R = \int_{t0}^{t0+Tlc} \frac{Q(t)}{Tlc}\, dt \quad (2)$$

Another study was conducted by Amy [7] to assess the preparedness of hospitals in Los Angeles. Verification of this survey study was conducted by on-site inspections. The number of hospitals surveyed in this study was forty five.

Khanmohammadi and Kashani [8] simulated events after an earthquake using Discrete Event Simulation and characterized the hospital behavior as well as the amount of post-incident demand while taking into account multiple uncertainties such as the degree of damage and the recovery process. Using their proposed model, they determined the impact of the patients' waiting time on their mortality rate. Also, the effects of the hazard and prolongation of waiting time on the structure of the society's economy are considered. Then a proper decision is made to increase the resilience of the hospitals.

Studies have shown that previous research has only looked at an isolated hospital and does not consider the effects of hospitals in a network as components of a system. The way a component acts affects the whole system. Post-incident events also are not simulated and optimized at the same time. Therefore, it is necessary to simulate events after the earthquake, to predict events in the network and then to optimize it.

3. Model

To quantify hospital network resilience, a framework has been designed, consisting of several models that are used step-by-step in the order shown in the figure below:

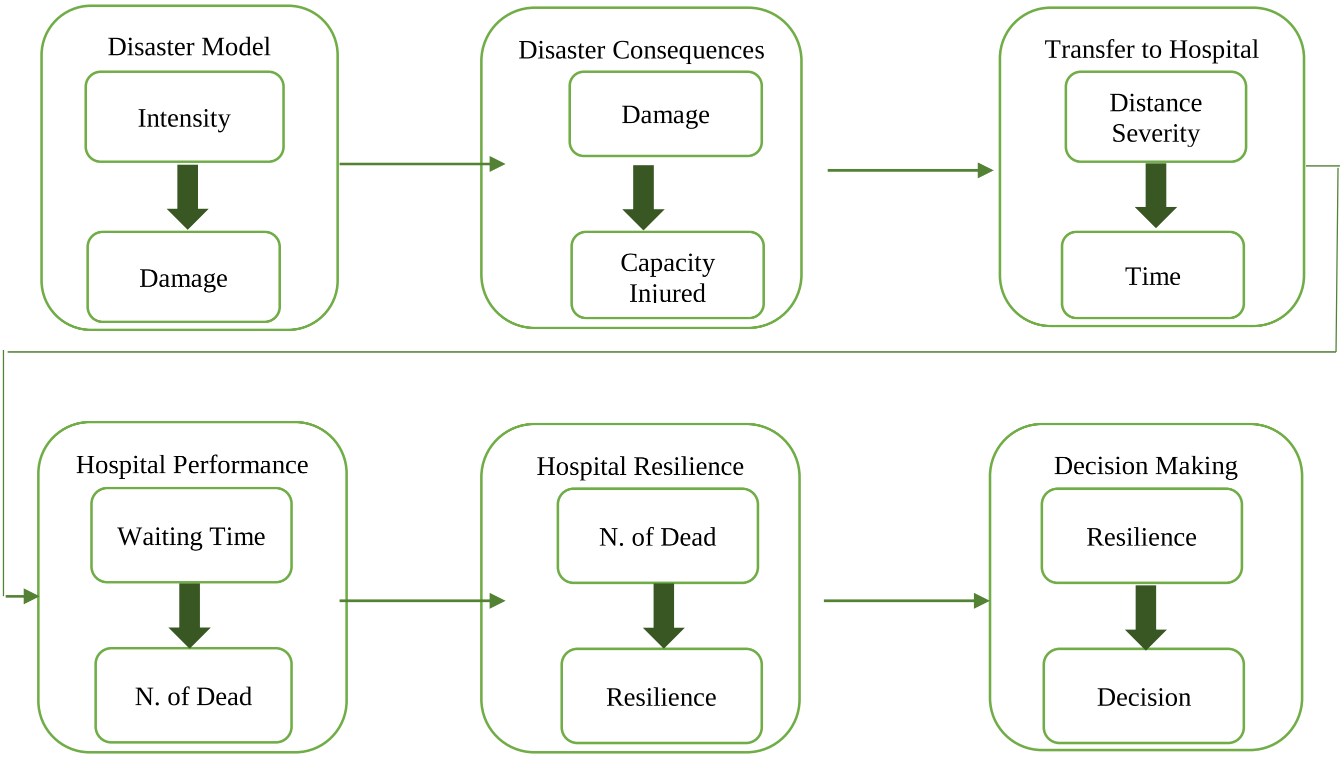

Fig. 2. Framework to calculate hospital network resilience.

Two of the most important components of the research are hospital accessibility and capacity. They influence patients' waiting time. Patients' waiting time determines the patients' situation in every moment. Other components are intensity of the hazard, quality of buildings and population of the region. These three components affect number of injured population. We also consider number of ambulances, road condition and traffic condition as effective components of time on way to hospital. Finally, quality of hospital performance is important in reducing waiting time and number of dead people. Resilience can be measured based on total dead number.

4. Example

Time and intensity of the model can be generated randomly but we considered that before the implementation of the earthquake model, an earthquake with assumed intensity and time had occurred. So earthquake intensity and its damage is known. Scenario sampling is used in this example. Since we need the number of wounded and the dead to run the model, the required initial data are obtained from Northridge earthquake in 1994. According to reports from Northridge earthquake, it can be concluded that the number of fatality in this earthquake is 33. The total population during the earthquake is estimated 8863164 people [10]. Then, the number of people in other level of injury can be obtained from HAZUS manual.

According to the HAZUS technical manual, the injured people are divided into four groups according to severity of injury, as shown in the table below [12]. Severity 4 shows fatality and from 1 to 3, severity becomes more. In table 2, the number of each group is calculated based on reports from Northridge earthquake. It is assumed that just a part of society is injured.

Table 1. Injury severity scale based on the HAZUS technical manual [12].

Injury Severity Scale	Ratio
Severity1	0.58
Severity2	0.10
Severity3	0.02
Severity4	0.30

Table 2. Number of each group of severity calculated based on reports from Northridge earthquake.

Injury Severity Scale	Ratio
Severity1	64
Severity2	11
Severity3	3
Severity4	33

Model is created in AnyLogic simulation software. It is assumed a lag between patients' arrivals because of the transportation network inefficiency. The standard deviation of the time between arrivals is high relative to mean because the after-incident condition of roads is uncertain. Other assumptions are:

- Three hospitals are in the region.
- Type 1 of severity can go three hospitals based on his condition.
- Type 2 of severity can go hospital two and three.
- Type 3 of severity first goes to hospital three. If the queue is long, patients will die.
- Type 4 of severity get immediate help in their initial place.
- If the queue of hospital one is long, patients will go to hospital two or will die.
- If the queue of hospital two is long, patients will go to hospital three or will die.
- Every hospital has doctor, nurse and triage nurse.

After running the model, the results are shown in figure3 and table3. Fig. 3.a. and 3.b. show number of dead people before and after earthquake. Fig. 3.c. and 3.d. show number of transferred patient before and after earthquake. The numbers after disaster are more than before it. It is obvious because the capacity of hospitals decrease and the number of patients increase. According to fig. 3.e. and 3.f., waiting time of hospital network dramatically increases after disaster. It can be understood that the resilience of the hospital network is not appropriate because number of dead and transferred patients are high in comparison to the total number of injured people. Waiting time of hospital one is also higher than others so it withstands more pressure. It can be concluded that one of the proposed suggestion for improvement of resilience is establishing a hospital around the hospital one. The advantage of the decrease in number of dead and the cost of building a new hospital or increasing its serviceability can be compared and the best decision can be made based on it. Fig. 3.g. shows the randomness of treatment time. It shows the uncertainty of after-incident condition.

Table 3. Average waiting time in each hospital.

Parameter	Result
Average Waiting Time of hospital one	17.24 min
Average Waiting Time of hospital two	13.10 min
Average Waiting Time of hospital three	10.56 min

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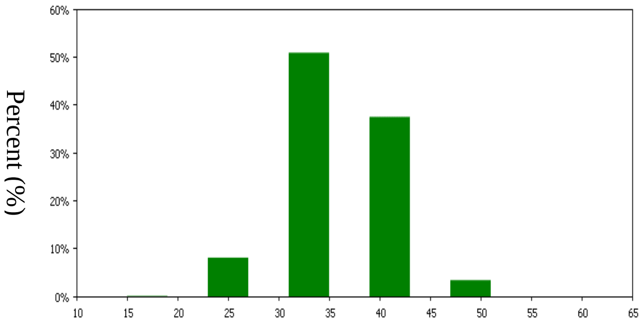
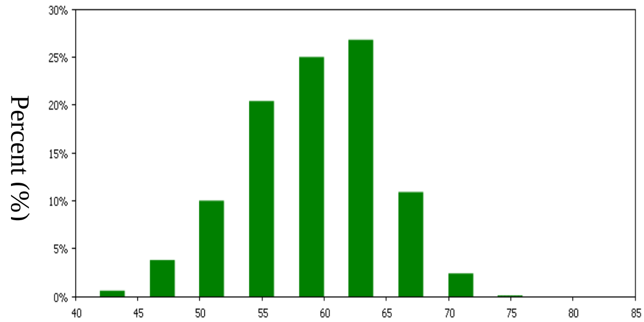
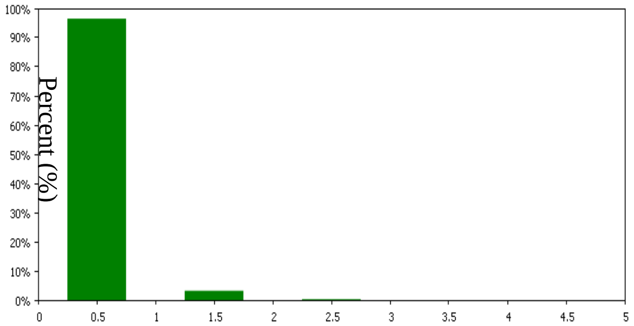


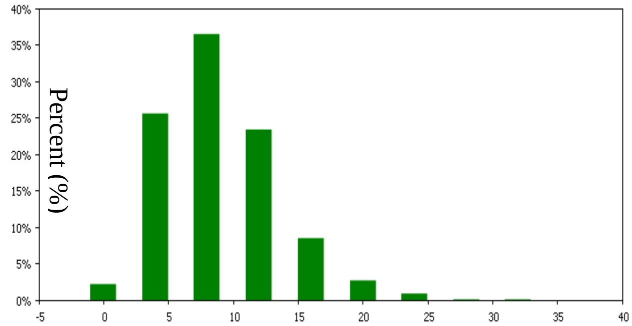
(a)
Number of Dead People
(Before Earthquake)



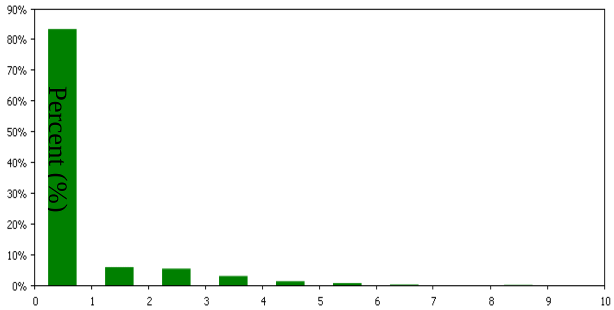
(b)
Number of Dead People
(After Earthquake)



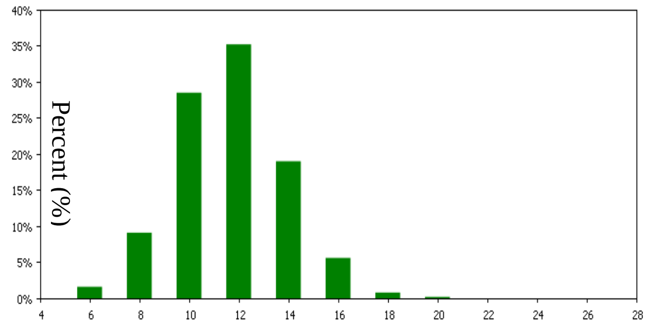
(c)
Number of Transferred Patient
(Before Earthquake)



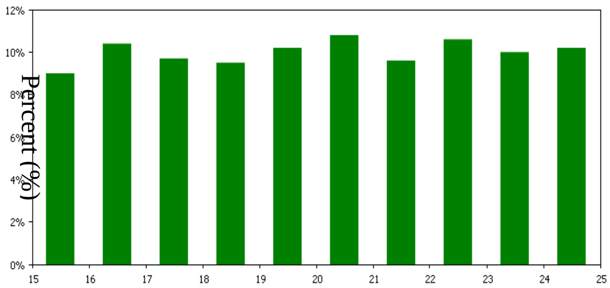
(d)
Number of Transferred Patient
(After Earthquake)



(e)
Network Waiting Time (min)
(Before Earthquake)



(f)
Network Waiting Time (min)
(After Earthquake)



(g)
Random Treatment Time (min)

Fig. 3. a) Number of dead people before earthquake, b) Number of dead people after earthquake, c) Number of transferred patient before earthquake, d) Number of transferred patient after earthquake, e) Network waiting time before earthquake (min), f) Network waiting time after earthquake (min), g) Random treatment time (min).

5. Conclusion

This paper puts forward as framework to evaluate the resilience of hospital networks. The resilience of hospital network in a community is among the most critical factors in reducing the losses caused by disasters. There is need for an appropriate index that can be utilized in order to evaluate and measure the resilience of hospital network and identify the opportunities for enhancing its resilience. In this paper, a hospital network resilience index was presented. A simulation framework was also introduced in order to measure the resilience of hospital network under uncertainties about the magnitude and consequence of hazard, response of various components of hospitals, and the performance of transportation network and lifelines such as electricity network.

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