Hospital Resilience to Earthquake-Induced Lifeline Interruptions

C Hansapinyo
Excellence Center in Infrastructure Technology and Transportation Engineering (ExCITE), Chiang Mai University, THAILAND

Corresponding author: chayanon@eng.cmu.ac.th

Abstract. Damage to lifeline system installed in a healthcare unit due to an earthquake will interrupt the medical operation. This study aims to assess the hospital resilience to the interruptions. A questionnaire was used as a tool to collect data from 362 persons working in the hospital. The data were analysed using descriptive statistics showing frequency, percentage, mean, and standard deviation. For the assessed lifeline systems, the electrical system is the most important lifeline system which will cause the operation suspension when disrupted. The estimated operable hour after the disruption of the systems was between 4.51-11.13 hrs. The information from this study can be used as a guideline for lifeline system management and readiness preparation to provide continuous medical services.

1. Introduction
Earthquake is a natural phenomenon which suddenly strikes an area causing damageable ground vibration. In the epicenter of a powerful earthquake, the direct damage of building collapse can be found. In addition, the quake can result in the indirect damage, for example, fires, landslides, lifeline system, business interruption, etc. Buildings in a seismicity area must be prepared to be strong to resist earthquake vibrations. It is especially to public buildings servicing a big group of people in a certain time. The hospital building is a very important one gathering injured people in the time of disaster. Hence, past researches have focused on the risk of damage to the building structures leading to a design guideline for the hospital building to be exceptionally strong. As the building collapse will lead to consequence losses, estimation of the structural damage under an assumed strong earthquake scenario have been done widely and incorporate into a decision making for the seismic risk preparedness plan [1-2]. For a sub-standard hospital building, as a highly important building, is prioritized to be strengthened before an earthquake. The building also needs an urgent repair after damaged by an earthquake under the risk management [3-4]. Most of the earthquake risk assessment research has been made based on an event of a powerful earthquake. However, under a non-violent earthquake, structural damage will not occur at the building. It may only damage systems or other non-structural building components which are more susceptible compared with the structural element. The operation of the hospital building essentially requires lifeline systems eg. electrical system, water supply system, wastewater treatment system, medical gas, communication system, air conditioning system, medical
Steam System etc. If the systems are affected by an earthquake, disruption of the system will interrupt or shutdown the medical operation of the hospital and services.

Joanne [5] studied the potential indirect economic impacts of lifeline disruption on businesses in Memphis, Tennessee in the United States. The investigated lifeline systems included electrical system, water supply system, Gas, Waste water and Communication. The questionnaire was distributed to 5 groups of business owners eg. retail, factory and construction, service, finance and others (Agriculture, Mining, Transportation etc.). The results of the study indicated the lifeline services problem to be prepared for a community recovery plan. For the study of non-structural damage of hospital building, Samsuddin [6] investigated the non-structural components influencing hospital’s disaster preparedness in Malaysia. The results indicated that the medical laboratory equipment and supplies for diagnostic and treatment were ranked first and required to perform its function during the disaster. Achour et al [7] explored major and potential challenges facing healthcare facilities operation. An estimation model was proposed to evaluate the impact of utility supplies interruption on the operation of healthcare facilities. Achour et al [8] investigated the damage to 34 healthcare facilities in seven countries caused by the past nine earthquakes. The investigation indicated that grid-based utilities eg. electricity, water supply and telecommunication were damaged and disrupted the healthcare activity. The utility damage of different earthquake events and different countries were similar due to the similar types of equipment and installations. Seismic code developed particularly to the utilities is crucial.

In this study, hospital resilience to earthquake-induced lifeline interruption was evaluated. The questionnaire was first designed and content consistency was evaluated. Then, the questionnaire was used to measure people attitude for rating the important level and downtime of the lifeline system. Maharaj Nakorn Chiang Mai was selected as a case study. The hospital is located in the Northern area of Thailand serving as the medical hub of the Northern Thailand and medical education as part of Faculty of Medicine, Chiang Mai University. Considering the seismicity, based on the geological survey and the past earthquake records, the area has been considered as an earthquake risk zone with moderate intensity. As being the major hospital in the area, earthquake-induced lifeline interruption affecting the medical services was determined. The results of the study will be used for the earthquake preparedness for the lifeline protection in order to continue crucial medical services.

2. Evaluation of hospital resilience to earthquake-induced lifeline interruptions

2.1 Method

In this study, seven lifeline systems installed in the hospital were evaluated. A questionnaire was distributed to the working people in the hospital. The information related to the important level of the lifeline system on the operation of the hospital was examined. There have been various kinds of rating scales developed to measure the personal attitudes. The most widely used is the Likert Scale (Likert [9]; Burns and Grove [10]). The people attitude are measured by asking people to respond to a series of statements about a topic in terms of the level of agreement. This study adopted the Likert frequency scales with a five-point scale to allow the individual to express the level of agreement on the importance level of the lifeline system, as shown in Table 1.

1. Electricity
2. Air Condition
3. Communication
4. Water Supply
5. Stream
6. Medical Gas
7. Water treatment
First, the quality test of the questionnaire was done and the content validity was evaluated. Then, the 362 questionnaires were submitted to three working groups of staff of the hospital eg. (1) Administration work, (2) Supporting service and (3) Patient Care Unit. The administration work deals with document work and administrative. The supporting service is defined as divisions working to support medical services such as food, equipment, blood bank, laboratory, etc. For the patient care unit, staff in this group contact directly with the patient.

Table 1. Likert’s rating scale,

| Level | Agreement     | Ordinal scales |
|-------|---------------|----------------|
| 5     | Strongly agree| 4.21 - 5.00    |
| 4     | Agree         | 3.41 - 4.20    |
| 3     | Neutral       | 2.61 – 3.40    |
| 2     | Disagree      | 1.81 – 2.60    |
| 1     | Strongly disagree | 1.00 – 1.80   |

2.2. Quality test of the questionnaire
The quality of the questionnaire was tested by 2 methods for the content validity and the content reliability.

2.2.1. Content validity evaluation. The content validity was evaluated using the index of item-objective congruence (IOC index) (Hambleton [11]; Rovinelli and Hambleton [12]). The method is based on the rating score for each specific objective listed by content experts. The rating score can be one of the following 3 scores as.

+1 for a clearly measuring content
0  for an unclear measuring content
-1 for clearly not a measuring content

The rating scores were then calculated for the IOC index by using Equation (1). The calculated content validity of this study was 1.0. The acceptable IOC index is at least 0.50.

\[ \text{IOC} = \frac{\sum R}{N} \]

Where

- \( \text{IOC} \) is the Item-Objective Congruence Index
- \( \sum R \) is the summation of the rating score
- \( N \) is the number of experts

2.2.2. Content reliability test. To measure the internal consistency of the surveyed items as a group, content reliability of the items was tested for repeatability through a pilot study with 30 questionnaires. The results from the pilot test were calculated for the content reliability index by Cronbach’s Alpha Coefficient using Equation (2) (Cronbach [13]).

\[ \alpha = \left( 1 - \frac{\sum \sigma_i^2}{n} \right) \left( 1 - \frac{\sum \sigma_i^2}{n-1} \right) \]

\[ \sigma_i^2 = \frac{\sum x_i^2}{n} - \frac{\left( \sum x_i \right)^2}{n} \]

\[ \sigma_i^2 = \frac{\sum \left( x_i - \bar{x}_i \right)^2}{n} \]
where $\alpha$ is the Cronbach’s Alpha reliability coefficient

\[ \alpha = \frac{N \bar{x} - \bar{x}^2}{\bar{x}_i - \bar{x}^2} \]

\[ \bar{\xi}^2 \] is the variation of total score

\[ x_i, \bar{x}_i, \bar{x} \] are the i score, the total score and the average score, respectively

The greater value of the alpha coefficient indicates the higher internal consistency of the test scores. The coefficient higher than 0.7 is a commonly accepted value (George and Mallery [14]). From the pilot study, the Cronbach’s Alpha coefficient was 0.803.

### 3. Results

#### 3.1 Important rate of the lifeline in the hospital

From the 362 total questionnaires measuring the people attitude, the important level (IL) of the lifeline system for the medical operation under normal condition is tabulated in Table 2. The number in the parenthesis is presented in the form of the percentage of the total 362 data. From the table, the average important level of the surveyed lifeline system is between 3.78-4.84 ranging from the “Strongly agree” to “Agree”. The working people “Strongly Agree” that the electricity is the most important lifeline system. The water treatment is the least important system. Considering the people attitude can be different with the different working group, hence, the attitude for the individual working group is presented, as shown in Table 3. From the table, all the working groups indicate the important level of the electricity as “Strongly agree”.

#### 3.2 Downtime evaluation

In addition to the prioritization of the lifeline system, the downtime after the shutdown of the systems was also evaluated. The downtime is a measure of the operable time from the shutdown of a lifeline system. As a medical operation requires coordination between other related units, average downtime obtained from the survey of the three working groups were presented, as shown in Table 4 and Figure 1. About sixty-four percent of the surveyed data identified the need for the electricity and the medical operation will stop suddenly without the provided electricity. Considering the average downtime, the medical services can continue without the supply of the lifeline system in between 4.51-11.13 hrs for the electricity system and the water treatment system, respectively.

| Table 2. The important level (IL) of the lifeline system for operation under normal condition. |
|---------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| **Lifeline**        | **Important level, number (Percent)** |                  | **Average** | **Standard deviation** | **result** | **Ranking** |
| Electricity         | Strongly agree  | Agree           | Neutral      | Disagree         | Strongly disagree |                  |                  |                  |
|                     | 313             | (86.5)          | 42           | (11.6)           | 5 (1.4)          | 1 (0.3)         | 4.84            | 0.463            | Strongly agree   | 1 |
|                     |                 |                 | 1 (0.3)      |                 |                   |                  |                  |                  |                  |
| Water supply        | Strongly agree  | Agree           | Neutral      | Disagree         | Strongly disagree |                  |                  |                  |
|                     | 216             | (59.7)          | 121          | (33.4)           | 21 (5.8)         | 2 (0.6)         | 4.51            | 0.671            | Strongly agree   | 4 |
|                     |                 |                 | 1 (0.3)      |                 |                   |                  |                  |                  |                  |
| Medical Gas         | Strongly agree  | Agree           | Neutral      | Disagree         | Strongly disagree |                  |                  |                  |
|                     | 262             | (72.4)          | 60           | (16.6)           | 32 (8.8)         | 6 (1.7)         | 4.59            | 0.766            | Strongly agree   | 2 |
|                     |                 |                 | 2 (0.6)      |                 |                   |                  |                  |                  |                  |
| Stream              | Strongly agree  | Agree           | Neutral      | Disagree         | Strongly disagree |                  |                  |                  |
|                     | 160             | (44.2)          | 112          | (30.9)           | 76 (21.0)        | 10 (2.8)        | 4.14            | 0.918            | Agree            | 5 |
|                     |                 |                 | 4 (1.1)      |                 |                   |                  |                  |                  |                  |
| Communication       | Strongly agree  | Agree           | Neutral      | Disagree         | Strongly disagree |                  |                  |                  |
|                     | 230             | (63.5)          | 99           | (27.3)           | 31 (8.6)         | 2 (0.6)         | 4.54            | 0.674            | Strongly agree   | 3 |
|                     |                 |                 | 2 (0.6)      |                 |                   |                  |                  |                  |                  |
| Air condition       | Strongly agree  | Agree           | Neutral      | Disagree         | Strongly disagree |                  |                  |                  |
|                     | 126             | (34.8)          | 118          | (32.6)           | 91 (25.1)        | 24 (6.6)        | 3.94            | 0.969            | Agree            | 6 |
|                     |                 |                 | 3 (0.8)      |                 |                   |                  |                  |                  |                  |
| Water treatment     | Strongly agree  | Agree           | Neutral      | Disagree         | Strongly disagree |                  |                  |                  |
|                     | 123             | (34.0)          | 98           | (27.1)           | 93 (25.7)        | 36 (9.9)        | 3.78            | 1.118            | Agree            | 7 |
|                     |                 |                 | 12 (3.3)     |                 |                   |                  |                  |                  |                  |
Table 3. Average attitude on the important level (IL) of the lifeline system from different working groups.

| Lifeline        | Administration work | Supporting service | Patient Care Unit |
|-----------------|---------------------|--------------------|-------------------|
|                 | Avg. IL  | Result  | Ranking | Avg. IL  | Result  | Ranking | Avg. IL  | Result  | Ranking |
| Electricity     | 4.90     | Strongly agree | 1       | 4.86     | Strongly agree | 1       | 4.83     | Strongly agree | 1       |
| Water supply    | 4.53     | Strongly agree | 3       | 4.44     | Strongly agree | 4       | 4.51     | Strongly agree | 4       |
| Medical Gas     | 4.20     | Agree    | 5       | 4.61     | Strongly agree | 2       | 4.59     | Strongly agree | 4       |
| Stream          | 4.00     | Agree    | 6       | 4.17     | Agree    | 5       | 4.14     | Agree    | 5       |
| Communication   | 4.67     | Strongly agree | 2       | 4.53     | Strongly agree | 3       | 4.54     | Strongly agree | 3       |
| Air condition   | 4.27     | Strongly agree | 4       | 3.94     | Agree    | 6       | 3.94     | Agree    | 6       |
| Water treatment | 3.90     | Agree    | 7       | 3.56     | Agree    | 7       | 3.78     | Agree    | 7       |

Table 4. Downtime evaluation after the lifeline shutdown.

| Lifeline System | Discontinue (%) | Continue (%) | Average downtime (hr) |
|-----------------|-----------------|--------------|-----------------------|
| Electricity     | 63.9            | 36.1         | 4.51                  |
| Water supply    | 48.0            | 52.0         | 7.41                  |
| Medical Gas     | 59.0            | 41.0         | 7.03                  |
| Stream          | 52.8            | 47.2         | 8.08                  |
| Communication   | 50.0            | 50.0         | 6.47                  |
| Air condition   | 51.2            | 48.8         | 7.12                  |
| Water treatment | 45.2            | 54.8         | 11.13                 |

Figure 1. Continuity and downtime after the shutdown of the lifeline systems.
4. Conclusions
This paper presents the study of hospital resilience to earthquake-induced lifeline interruptions. From the study, Electricity is the most critical lifeline system. The electricity shutdown will cause the disruption of the medical operation. Water supply, Gas system and communication are respectively important to the continuous operation. The mentioned lifeline systems are classified as the extremely important systems. Stream, air condition and waste water treatment systems are respectively identified with the important rating scale. Considering the average downtime, the medical services can continue without the supply of the lifeline system in between 4.51-11.13 hrs for the electricity system and the water treatment system, respectively. As the medical services have heavily relied on the lifeline system, a reserved system is required to be able to operate normally under an earthquake event.

References
[1] Tesfamariam S and Goda K 2013 Handbook of Seismic Risk Analysis and Management of Civil Infrastructure Systems Woodhead Publishing p 912
[2] Franchin P, Pinto P E and Schotanus M I J 2006 Seismic Loss Estimation by Efficient Simulation Journal of Earthquake Engineering 10 pp 31-44
[3] Saicheur K and Hansapinyo C 2017 Seismic Loss Estimation and Reduction after Structural Rehabilitation in Chiang Rai City Walailak Journal of Science and Technology 14 6 pp 485-499
[4] Saicheur K and Hansapinyo C 2016 Structural repair prioritization of buildings damaged after earthquake using fuzzy logic model Journal of Disaster Research 11 3 pp 559-565
[5] Joanne M N 1996 Anticipated Business Disruption Effects due to Earthquake-Induced Lifeline Interruptions Post-Earthquake Rehabilitation and Reconstruction Elsevier Science pp 47-57
[6] Samsuddin N M, Takim R, Nawawi A H, Rosman M R and SyedAlwee S N A 2018 Non-structural Components influencing Hospital Disaster Preparedness in Malaysia IOP Conf. Ser.: Earth Environ. Sci. 140 012007
[7] Achour N, Miyajima M, Pascale F and Price A 2014 Hospital Resilience to Natural Hazards: Classification and Performance of Utilities Disaster Management and Prevention 23 1 pp 40-52
[8] Achour N, Miyajima M, Kitaura M and Price A 2011 Earthquake Induced Structural and Nonstructural Damage in Hospitals Earthquake Spectra 27 3 pp. 617-634
[9] Likert R 1932 A Technique for the Measurement of Attitudes Archives of Psychology 140 pp1–55
[10] Burns N and Grove S K 1997 The Practice of Nursing Research Conduct, Critique, & Utilization W.B. Saunders and Co., Philadelphia.
[11] Hambleton R K 1978 Criterion-referenced testing and measurement: A review of technical issues and developments Review of Educational Research 48 pp 1-47
[12] Rovinelli R J and Hambleton R K 1977 On the use of content specialists in the assessment of criterion-referenced test item validity Dutch Journal of Educational Research 2 pp 49-60
[13] Cronbach L J 1951 Coefficient alpha and the internal structure of tests Psychometrika 16 pp 297-334
[14] George D and Mallery P 2003 SPSS for windows step by step: A simple guide and reference 11.0 Update (4th ed) Boston: Allyn&Bacon.