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A Simplified Analytical Model to Evaluate Hospital Preparedness for Earthquake Emergency Response

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ABSTRACT: Casualty management is crucial after an earthquake disaster. A comprehensive emergency response plan is essential for all sectors, especially in emergency healthcare services, to reduce the fatalities and maximize the number of saved lives after a mega-earthquake disaster. Post-earthquake emergency healthcare services greatly depend on the level of hospital preparedness. This research proposed a simplified analytical model to evaluate hospitals' preparedness for earthquake emergency response. The proposed model considers the number, severity, and distribution of injuries in the affected region, as well as the seismic vulnerability, hospitals' existing resources, and the timeline. The model can predict different levels of preparedness for different numbers of casualties and estimate the number of saved lives. In a case study of Dhaka Medical College Hospital, for damage state grades 1 and 2, a dynamic range of results have been discovered where a sufficient level of preparedness can be observed for a lower number and an insufficient level of preparedness for a higher number of casualties. In addition, we observed that prioritization of casualty treatment could significantly change the hospital preparedness level. Emergency managers and policymakers can utilize the proposed model to determine hospital preparedness levels and take the required actions to bridge the gap between post-earthquake hospital demand and capacity.

Keywords: Earthquake Emergency Response; Analytical Model; Hospital Preparedness; Casualty Treatment

INTRODUCTION

Since the last decade, the frequency of unexpected disasters has increased, which has alleviated the mortality rate (≈ 106000 people per year) worldwide (Munich Re, 2012). Earthquake disasters are known to be highly catastrophic, considering the number of casualties, social trauma, and tremendous damage to physical properties and lives. According to United Nations International Strategy for Destruction Reduction (UNISDR), in the last 20 years, 1.35 million people have been killed by natural hazards, half of whom have died due to earthquake disasters (Centre for Research on the Epidemiology of Disaster and the United Nations Office for Disaster Risk Reduction, 2016). Earthquakes have caused approximately 27,000 deaths yearly since 1990 (Guha-Sapir and Vos, 2011). Moreover, large-scale catastrophic events like earthquakes pose significant challenges to the emergency response system, especially in the healthcare system, evidenced by the positive correlation between response time and mortality rate. Approximately 20% to 50% of casualties can be saved if the severely injured people receive proper treatment in the first six hours following an earthquake (Aoki *et al.*, 2004). Reducing response time and patients waiting time for treatment after an earthquake can drastically increase the number of saved lives, which is the primary goal of earthquake emergency response.

The casualty's healthcare facilities play a critical role in reducing the waiting time and, consequently, saving more lives after the extrication of earthquake victims. During an emergency, a hospital's role is not only to provide medical care but also to save patients (Mulyasari et al., 2013). Hence, to meet the needs of the affected community, all the hospitals must be able to withstand hazards and remain functional. However, disasters often cause massive disruptions to hospital systems by damaging their supporting infrastructure and, as a result, reducing their functionality (Fawcett and Oliveira, 2000). For example, the 1999 Turkey Earthquake ((7.6 magnitude) caused ~50,000 injuries

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and disrupted the services of ten major hospitals leading to grave concern (Ceferino *et al.*, 2020).

In some cases, hospital infrastructures may be structurally safe; however, their functionality decreases from their standard capacity due to resource constraints (staff, equipment, utilities, or increased number of patients) (Mulyasari et al., 2013). For example, due to a high influx of patients after an earthquake, there is a mismatch between hospital capacity and demand (Fig. 1). Such mismatch creates an imbalance in the hospital's capacity; thus, the number of saved lives will decrease due to longer waiting times (Ceferino *et al.*, 2020).

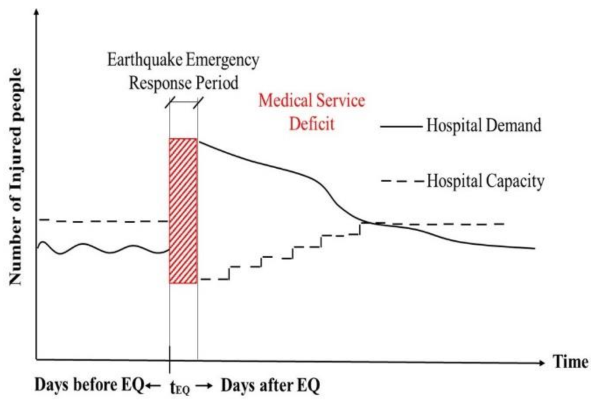


Figure 1: Medical Service Deficit during the Earthquake Emergency Response Period (Modified from Ceferino et al., 2018)

To solve the problem of structural and functional failure of a hospital prior to a catastrophic event, an evaluation of the hospital's preparedness is crucial to make it resilient. A well-prepared hospital, which has addressed its structural, functional, and operational vulnerability, can save more lives by functioning efficiently.

Importance of a Safe Hospital

Making hospitals and health facilities resilient and safe is critical for a country's economic prosperity. Hospital preparedness is a social, moral, and ethical necessity of life because the required cost for making the hospital safe from disaster is significantly lower than the payable amount in the case of the failure of the hospital (Bajow and Alkhalil, 2014). Safe hospitals are those in which services remain accessible and can function at maximum capacity and also within the same infrastructure during emergencies or immediately after a disaster (WHO, 2009). Sometimes, hospitals become purposeless due to their structural and functional failure after a hazard. As a result, they become incapable of serving at the time of utmost need (Mulyasari et al., 2013). Following a large earthquake, the number of severely injured victims abruptly rises. As a result, the hospital's capacity to give treatment decreases which causes a secondary calamity that will not allow patients to be treated promptly or properly. The gap between demand and capacity after an earthquake is highly dynamic because it depends on the recovery of hospital functionality. Hospitals should be prepared to keep pace with the increasing demand and additional stresses for healthcare services and serve as many people as possible (Ceferino et al., 2018).

Hospital Disaster Preparedness (HDP) guarantees hospital resiliency and functionality during disasters, resulting in reduced overall mortality and morbidity and an increased number of saved lives; hence, a good response can be achieved (Ingrassia *et al.*, 2016). It is not an instant process but rather an ongoing one where there is always a scope for improvement. Therefore, a proper methodology is direly needed to measure hospitals' preparedness. Hospitals' preparedness means taking measures to prepare and play an influential role in the response, reducing the effects of disaster, and saving as many lives as possible in an emergency event. According to FEMA (Federal Emergency Management Agency), preparedness is a continuous cycle of planning, organizing, training, equipping, exercising, evaluating, and taking corrective measures to ensure effective coordination during emergency response. In other words, preparedness is the knowledge and capacities developed by governments, response and recovery organizations, communities, and individuals to effectively anticipate, respond to, and recover from the impacts of likely, imminent, or current disasters (Samsuddin *et al.*, 2018). Therefore, it is clear that evaluating preparedness is a critical phenomenon that must be done regularly to ensure a good response. Several methods and tools are being applied to evaluate the hospitals' preparedness at present. Some frequently used tools are listed in Table 1.

Table 1: Frequently used Existing Hospital Preparedness Tools

Source	Type of instrument	Disaster types
World Health Organization (WHO) (WHO, 2011)	Checklist	All
Pan American Health Organization (PAHO, 2008)	Checklist	All
WHO (Europe) (WHO, 2007)	Handbook	Earthquake
(Bajow and Alkhalil, 2014)	Questionnaire	Earthquake
(Ardalan *et al.*, 2014)	Questionnaire	All

Among all these instruments, the WHO checklist is the most widely used. In all of these instruments, structural, non-structural, and functional features are either addressed separately or in combination through questionnaires, surveys, and checklists. None of these instruments have considered the number of casualties to evaluate hospitals' preparedness level. However, a hospital's preparedness levels cannot be fixed for the different levels of earthquake disasters as preparedness level broadly depends on the number of casualties.

The relationship between the number of casualties and hospital preparedness level is absent in almost all these instruments. To evaluate this dynamic behavior, a model is needed to consider the number of casualties. Hence, predicting the number of casualties is a prerequisite to assessing hospitals' preparedness. For calculating the number of casualties after an earthquake, some established prediction models or methods exist, i.e., mortality prediction due to building collapse (Coburn et al., 1992), casualty prediction method considering burial and rescue (Fang *et al.*, 2020), etc. Moreover, predicting casualties is critical for planning and preparing for an efficient and effective emergency response. Among these, some casualty models solely consider the number of deaths (Coburn et al., 1992) without considering different types of injury levels. For example, casualty prediction models based on partial Gaussian curves considered five essential indices: magnitude, epicenter intensity, population density, damage building area, and time (Huang and Jin, 2018). However, HAZUS (Hazards United States (FEMA)) and PAGER (Prompt Assessment of Global Earthquakes for Response) use casualty models without considering multi-severity (Spence et al., 2011). Therefore, a multi-severity casualty model could be an excellent choice to get a clear picture of the situation after an earthquake (Ceferino et al., 2018).

Structural vulnerability assessment is also an essential component in estimating the level of hospital preparedness. WHO Europe has developed a handbook for seismic vulnerability assessment for health facilities (WHO, 2007) that can be used for this purpose.

Hospitals' preparedness depends on their capacity to serve, which again depends on the existing resources and alternative resources to respond rapidly after an earthquake. An earthquake-resilient hospital should be well prepared. A resilient hospital means having the absorptive capacity to withstand at the time of an earthquake, having the adaptive capacity to perform using alternative resources, and having the restoration capacity to recover fast (Vugrin *et al.*, 2015).

This study aims to develop a novel analytical model to assess post-earthquake hospital preparedness levels to bridge the gap between the number of casualties and hospital preparedness. The analytical model considered critical components of hospital preparedness, such as multi-severity casualties, structural vulnerability, hospital resources, and time.

METHODOLOGY

This section illustrates a simplified analytical model for evaluating hospital preparedness for earthquake emergency response that can be used to assess post-disaster hospital preparedness for different casualty numbers. Moreover, this model can reduce waiting times for disaster patients by determining the hospital's capacity in relation to its resources (Jat and Rafique, 2020). The model consists of three main components: input (scenario inputs, system input), system, and output. Figure 2 shows the flow chart of the simplified analytical model.

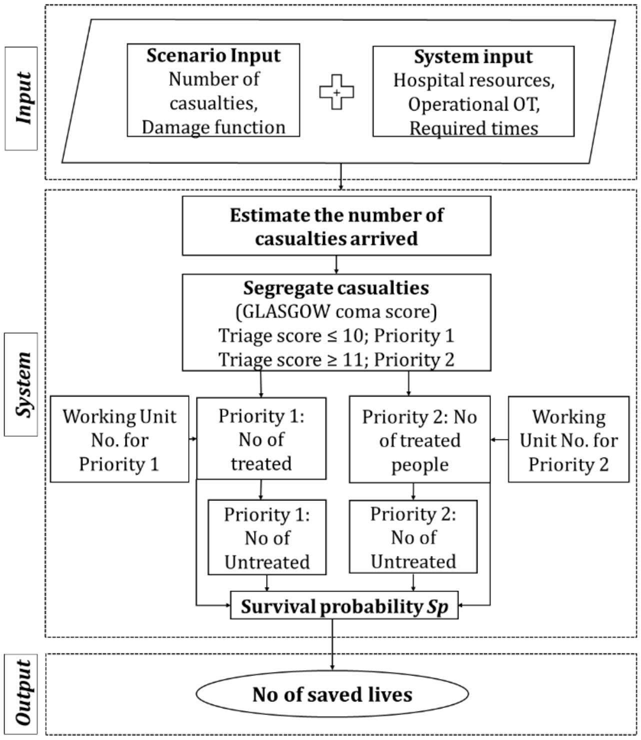


Figure 2: Flow Chart of the Proposed Analytical Model to Evaluate Hospital Preparedness for Earthquake Emergency Response

Input

This model has two inputs: scenario input and system input. Further details of each input are given below:

Scenario Input

The scenario input consists of the number of casualties and damage function of hospital buildings. The number and severity of casualties depend mainly on earthquake intensity. Typically, most earthquake victims are minor to moderately injured (Shoaf *et al.*, 1998). However, treatment varies greatly depending on the severity of the casualties. Thus, evaluating the spatial distribution of multi-severity earthquake casualties is a prerequisite to determining the community's healthcare system demand. Existing established approaches for estimating earthquake casualties mainly consider the earthquake magnitude and location, the structural vulnerability of buildings, and occupancy dynamics. Here, we have adopted the probabilistic model proposed by Ceferino et al., 2018 (Fig. 3).

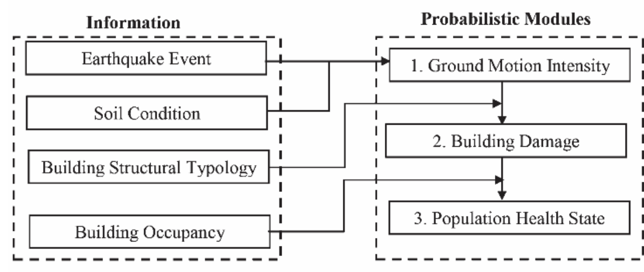


Figure 3: Flow Diagram of the Multi-severity Casualty Model Framework (Adopted from (Ceferino et al., 2018)

The second module of scenario input is the damage function. Seismic vulnerability assessment of hospitals' structures is crucial in evaluating preparedness. Therefore, it is necessary to perform a more detailed structural vulnerability analysis to assess the expected damages to the facility and its seismic performance and take necessary steps (retrofit, reconstruction) to keep it functional during emergencies (Guragain et al., 2009). The basic steps to perform structural vulnerability analysis are 1. structural response estimation, 2. developing fragility models, and 3. an assessment of the expected damage grade and facility performance. From the analyses, the fact can be identified that the building might experience negligible to slight damage or heavy damage that may result in complete loss of facility function (WHO, 2007). In the proposed model, we have adopted the damage scale proposed by (Hill and Rossetto, 2008) (Table 2). However, we have assumed that if the hospital faces no damage, the model will work further as the hospital will be functional; for slight non-structural damage, functional efficiency will be decreased to some extent. However, if the hospital structure encounters moderate or heavy structural damage, the hospital needs to be evacuated immediately.

Table 2: Damage Scale (Hill and Rossetto, 2008)

Damage State	Damage Title
Grade 1	Negligible to slight damage
Grade 2	Moderate damage
Grade 3	Substantial to heavy damage
Grade 4	Very heavy damage
Grade 5	Destruction

System Input

System input of the proposed model includes hospital resources, OT (operation theater), and required time for treatment based on a literature review and expert opinion. These components work together as a system to respond during an emergency.

The preparedness elements are the availability of qualified medical personnel, appropriate space, essential equipment, etc., which are considered to be the dependent factors for the ability of a hospital to cope with disaster and mass casualty (Ingrassia *et al.*, 2016). Identifying the availability of the hospital's resources is very much needed as it will play a crucial role at the time of any disaster. If the hospital's capacity can be identified based on its resources, the waiting time for severely injured patients can be reduced (Jat and Rafique, 2020). The resources we have considered to estimate the preparedness are the hospital's doctors, nurses, ward boys, backup of electricity, oxygen (O2) plant, alternative sources of water and gas supply, hospital's drug storage with available stock, available instruments for giving treatment, functional operation theater (OT), etc. It is a prerequisite to ensure the presence of all hospital rsources to serve during an emergency.

During an earthquake emergency, the demand for healthcare facilities spikes, causing a mismatch between capacity and demand. Therefore, to serve all the severely and moderately affected patients and to meet the surge in a hospital, it is critical to assess a fully functional OT (operation theatre). However, Ceferino *et al.* (2020) mentioned that after an earthquake, on average, 48% of OT will be functional. Therefore, identifying a fully functional OT is essential for good preparedness.

Finally, the third component is the required time for providing treatment, which is one of the most critical components following an earthquake to estimate hospital preparedness. As soon as the casualties are treated, their chances of survival increase and, consequently, the number of saved lives. In this study, we have considered 2.5 and 0.5 hours to give treatments to priority 1 and 2 injured victims, respectively, based on expert opinion. After ensuring structural safety, to get the highest functional efficiency of a hospital during an earthquake emergency, the following pre-conditions should be present at the hospital (Table 3)

Table 3: List of all the Resources which are needed for Efficient Response

Pre-condition	**Yes**	**No**
Back up of electricity	✓	
Oxygen plant	✓	
Alternative Water supply (deep tube well)	✓	
Gas supply	✓	
Fire extinguisher	✓	
Telephone	✓	
Own Drug storage with available drug stock	✓	
Instrument availability (Saline set, blood set, blood bag, Intravenous (I/V) canula, I/V fluid, umbo bag, CT drain, endotracheal (Et tube), etc.)	✓	
Supportive instrument availability	✓	
Functional OT with all emergency support	✓	
Available Human Resource (24 hours)	✓	
Basic life support and Advanced trauma life support, training of the health staff to get the highest efficiency	✓	

SYSTEM

Estimating the Number of Casualties to Arrive at a Hospital

The first step of the system is to estimate the number of casualties that may arrive at a hospital during an emergency. The types and numbers of casualties will differ for the different earthquake intensities in the affected area. Therefore, firstly, we have to estimate the number of casualties using an appropriate model. The arrival of untreated casualties depends on the hospital's attractive resources and distance from the affected area. In this study, we have adopted the model proposed by (Fawcett and Oliveira, 2000), where the attractiveness of the hospital depends on the hospital's resources as well as the treatment capacity of the hospital during an emergency period. The equation to estimate the number of casualties arrived at a hospital is given in Eq. 1.

$$c_{ij} = (C_i * \frac{A_j * e^{-\lambda . t_{ij}}}{N_j}) \qquad \text{(Fawcett and Oliveira, 2000)} \qquad \textbf{(1)}$$

Where,

c_{ij} = Number of casualties that move from origin zone i to j

C_i = Number of untreated casualties in zone i

A_j= Attractiveness of zone j

ρ = Calibration parameter for the reluctance to leave a hospital queue

$\boldsymbol{\lambda}$ = Calibration parameter for the effect of distance

t_{ij}= Time to travel from zone *i* to zone *j*

N_j= Normalizing factor to ensure that $\sum_j c_{ij} = C_i$

After the arrival of casualties, the hospital's system will function effectively if the hospital is prepared enough. However, there are situations when a large influx of patients overwhelms the hospital's activities due to a lack of preparedness. Therefore, before the emergency occurs, the estimation of casualties is essential to prepare the hospital. When estimating the number of victims, it should be kept in mind that every hospital contains some patients who are receiving care prior to the incident. The casualty influx with time is given in Eq. 2.

$$\text{Causality Influx, } C_{IT} = c_{ii} + (c_{ij} - c_{ii})\left(\frac{t}{t_p} * e^{\left(1-\frac{t}{t_p}\right)}\right)^{\frac{c_{ij}}{t_p}} \quad (2)$$

Where,

c_{ii}= Initial number of patients

c_{ij}= Max number of patients

t= Time

t_p= Time of peak when the number of patients is the most

Segregate Casualties According to the Severity

After estimating the number of casualties arrived at a hospital, it is required to divide them into groups based on the 'triage number.' According to the Oxford definition, triage is the process of assigning degrees of urgency to wounds or illnesses to determine the treatment sequence for a large number of patients or casualties. Even though nowadays, triage refers to the classification of patients based on the severity of their injuries. There are different mechanisms for mass casualty triage, among which we have considered 'GLASGOW COMA SCORE (GCS) in this study (Fig. 4). This scale describes the extent of impaired consciousness in all types of acute medical and trauma patients within a short time.

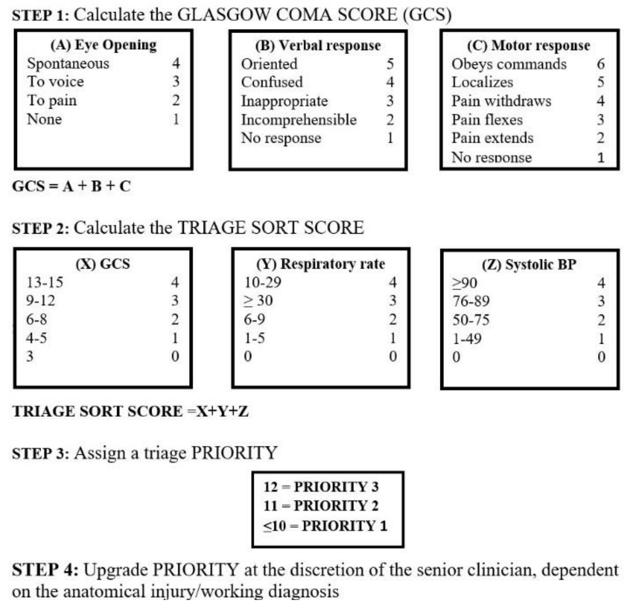


Figure 4: Glasgow Coma Score

This scale could be used to segregate severely injured patients who need OT facilities from slightly injured patients. Using this score, the improvement or deterioration of patients can be easily identified at the time of mass casualties, and the decision can be taken easily about the line of treatment (treatment priority). In the proposed model, when the triage score is ≤ 10 according to GCS, we considered them as 'Priority 1';when the triage score is ≥ 11, they were considered 'Priority 2'.

Number of Treated and Untreated People

After segregating the severely injured victims who need immediate OT support from the total casualties, we can estimate the 'number of treated people' as priority 1 and priority 2 groups at any time by using Eq. 3 and 4, respectively

The number of treated people (Priority 1):

$$T_{p1} = \frac{t(h) \times U_{p1}}{2.5(h)} \quad (3)$$

The number of treated people (Priority 2):

$$T_{p2} = \frac{t(h) \times U_{p2}}{0.5(h)} \quad (4)$$

Where,

t = time which is a variable;

U_{p1} = working unit number for priority 1 victims

U_{p2} = working unit number for priority 2 victims

Several factors must be considered in determining the working unit number for seriously injured patients (priority 1 victims). For example, surgery cannot be performed without the presence of a surgeon and anesthetist. In addition, medical staff cannot perform efficiently after 8 hours (Fawcett & Oliveira, 2000). However, in the event of an emergency, we anticipate that they will work for 12 hours in one shift and then be replaced by another workforce. As a result, we have divided the number by two to account for two shifts when identifying the unit. We must also consider the number of assistant doctors, n_a , the number of ward boys, n_w, and the number of nurses, n_n to assist in the surgery while identifying the number of working units. In most healthcare facilities in Bangladesh, the numbers of nurses and ward boys are significantly higher than the number of doctors. As a result, we did not consider their number while determining the working unit number.

The final element is the number of functional OT, n_{OT}. No major operation may take place without a well-functioning OT. We have not divided n_{OT} by two because continuous operations can be carried out if the resource stocks are available. In this study, the working unit numbers for priority 1 victims are given in Eq. 5.

$$U_{p1} = min \parallel n_{OT}, \frac{n_s}{2}, \frac{n_a}{2}, \frac{n_{ad}}{2} \parallel \quad (5)$$

As mentioned earlier, an operation cannot be performed without the presence of an OT, surgeon, anesthetist, and assistant doctor. Therefore, to figure out the unit number, based on the staff's 12-hour efficiency, we shall use 2.5 hours as the minimum amount of time to complete an operation by a working unit. We can get the number of untreated people by subtracting the total treated people from the total severely injured people (Eq. 6).

Priority 1: No of untreated people = $Total_{p1}$ - $Treated_{p1}$ (6)

The same procedure was followed for the slightly injured 'priority 2' patients, whose unit number is determined by the number of doctors available. To serve these patients during an emergency, a working unit consisting of at least one doctor, a nurse, or a ward boy can be formed.

In this study, the working unit numbers for priority 2 victims are given in Eq. 7, and the number of untreated victims is given in Eq. 8.

$$U_{P2} = \min \parallel n_d \parallel \quad (7)$$

Priority 2: No of untreated people =

$$Total_{p2} - Treated_{p2} \quad (8)$$

Survival Probability

The available data in a country that has recently experienced an earthquake and has statistics on the survival probability of various sorts of injured persons can be utilized to produce a more precise and local survival probability. Bangladesh has not faced any earthquakes in recent times. Due to a lack of data regarding different injury compositions and survival probability functions in Bangladesh, the injury composition ratio and life-span-characteristics-function of entrapped occupants of Kobe City in the Great Hanshin-Awaji Earthquake data (Ohta *et al.*, 2004) have been considered. Table 4 and figure 5 show the composition ratio by the level of injury and life-span-characteristics-function for the Kobe earthquake in 1995.

Table 4: Composition Ratio by the Level of Injury and Life-Span-Characteristics-Function for the Kobe Earthquake 1995

Injury Level	Composition ratio in Kobe city in the Great Hanshin-Awaji Earthquake	Life-span-characteristics-Function [t=time(h)]
Death/Dying	2%	$e^{[-(t/0.092)^{3.71}]}$
Serious injury	11%	$e^{[-(t/3.324)^{3.71}]}$
Medium injury	23%	$e^{[-(t/12.300)^{3.71}]}$
Slight injury	30%	$e^{[-(t/26.590)^{3.71}]}$
Uninjured	34%	$e^{[-(t/66.480)^{3.71}]}$

Due to the unavailability of data, the study assumptions are based on Kobe earthquake life span characteristics. It assumes that about 11% of seriously injured patients and 23% of moderately injured patients would require OT support (Priority 1). According to literature, if seriously and moderately injured earthquake victims receive competent treatment during the first hours, a lot of patience may survive (Sampalis *et al.*, 1993).

With the help of expert opinion, we have also considered that when entrapped occupants are rescued, their survival probability could be increased by around 20% due to the availability of oxygen, water, and other factors. Therefore, to understand the survival function's behavior,' we considered four hypothetical instances, where there are 5%, 10%, 15%, and 20% increases in each of these circumstances (Fig. 6).

Another assumption was made for the treated patients. After receiving timely treatment, the survival probability is increased to 50-80 percent. Therefore, we have considered 4 cases, which are 50%, 60%, 70%, and 80%, to see the worst, two intermediate, and the best-case results after getting treatment (Fig. 7).

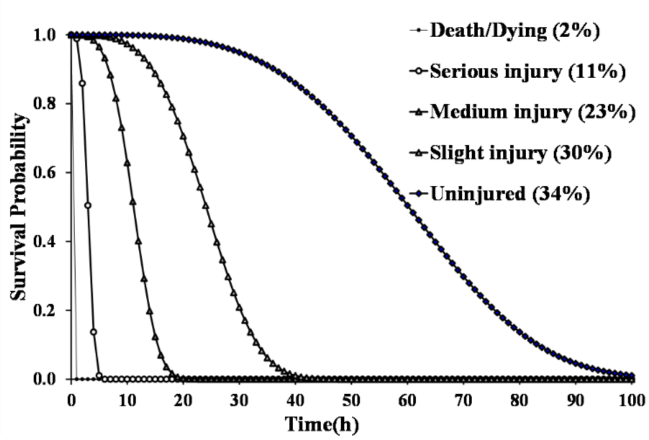
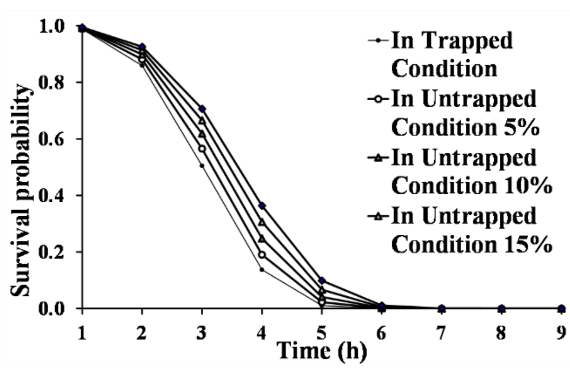
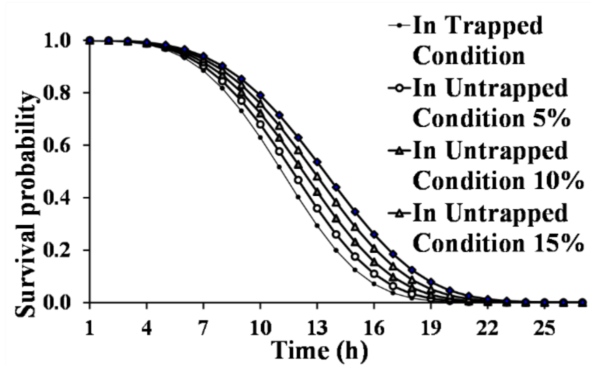


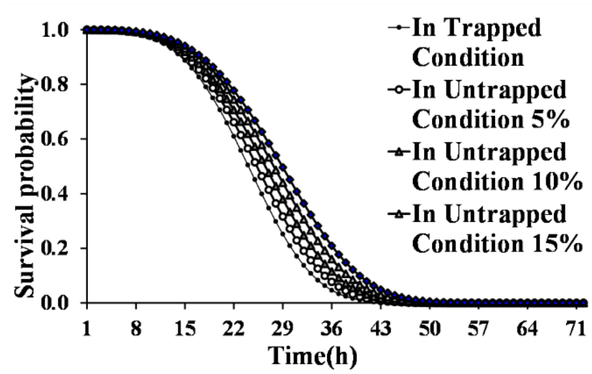
Figure 5: Survival Probability of Kobe Earthquake 1995 for Different Types of Casualties in Trapped Conditions



(a)

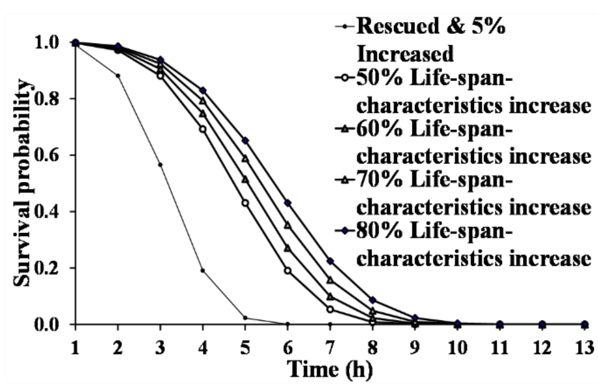


(b)

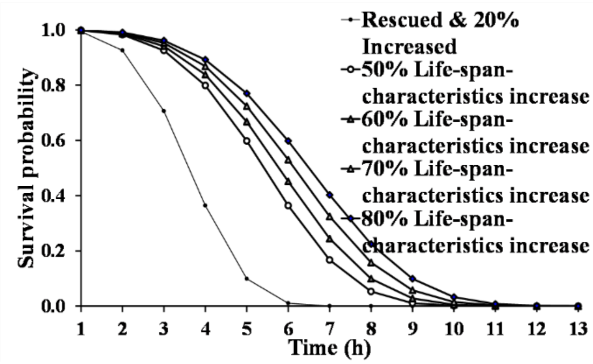


(c)

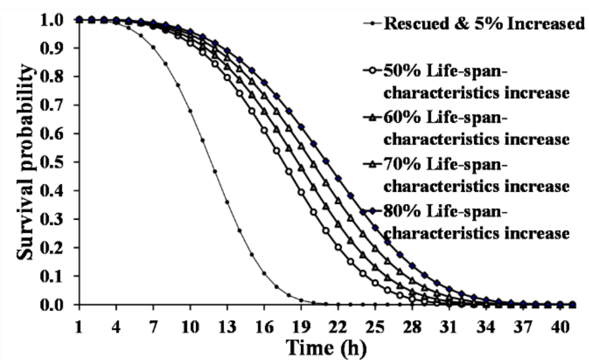
Figure 6: Survival Probability Increased after Being Rescued from Entrapped Conditions (a) Severely Injured, (b) Medium Injured, and (c) Slightly Injured Victims



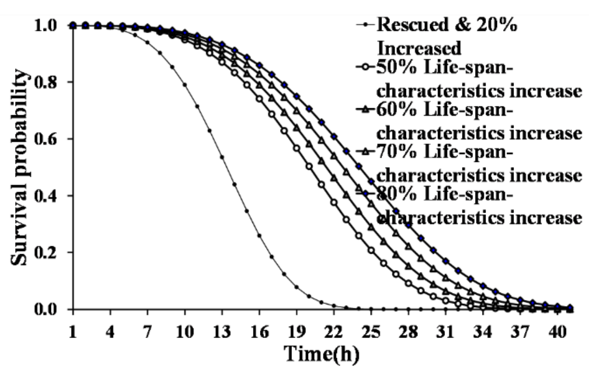
(a) Worst Case Scenario for Severely Injured Victims



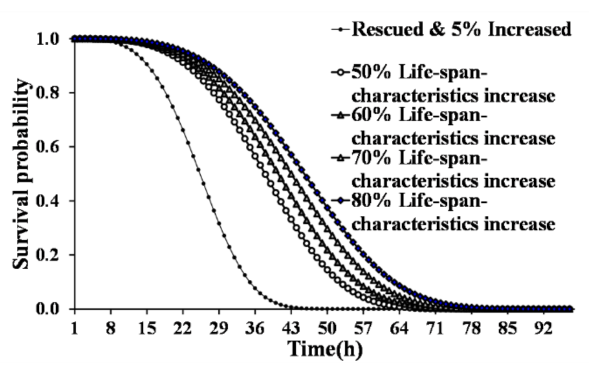
(b) Best Case Scenario for Severely Injured Victims



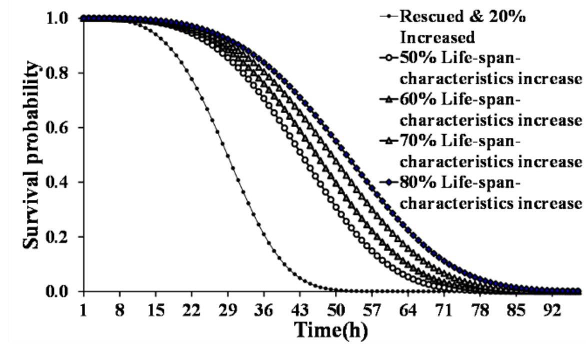
(c) Worst Case Scenario for Moderately Injured Victims



(d) Best Case scenario for Moderately Injured Victims



(e) Worst Case Scenario for Slightly Injured Victims



(f) Best Case Scenario for Slightly Injured Victims

Figure 7: Best and Worst-case Scenarios of Severely, Moderately, and Slightly Injured Victims Considering the Increase in Survival Probability

Nonetheless, when using the survival probability, an earthquake-prone country should use its data as it can vary from country to country due to its structural vulnerability, poverty, socio-economy, weather conditions, etc. Here we have considered the survival probability derived from the Kobe earthquake of 1995.

Output

The final output of the model is the number of saved lives for a particular hospital. We estimated the number of saved lives by multiplying the survival probability function and the number of treated and untreated victims at each time (Eq. 9).

No of saved lives $=(T_{p1}, T_{p2}, UT_{p1}, TU_{p2}) \times S_p$ (9)

Where,

T_{p1}=No of treated priority 1 victims

T_{p2}=No of treated priority 2 victims

UT_{p1}=No of untreated priority 1 victims

UT_{p1}=No of untreated priority 2 victims

S_p= Survival probability

MODEL VERIFICATION

This study has considered the preparedness condition of Dhaka Medical College Hospital (DMCH), Bangladesh, to respond after an earthquake. However, due to the lack of data, we have verified using the all-hazards tool for hospital administrators and emergency managers to estimate the level of preparedness, which is the 'Hospital emergency response checklist' developed by the World Health Organization (WHO)(World Health Organization, 2011). For this purpose, all the data of DMCH was collected by a questionnaire survey.

This checklist has nine key components and ninety-two recommended actions to estimate preparedness. The value for each action is zero ("due for review" action did not exist), one ("in progress" existed but still not completed), and two ("completed"). We have collected all of these data from the hospital personnel and calculated the score against each action. The highest possible score is 184. According to the score, the level of preparedness can be categorized as unacceptable preparedness (0-64), insufficient preparedness (65-129), or sufficient level preparedness (130-184) (Naser et al., 2018).

However, when the hospital meets less than 35% of the requirements, we consider the preparedness level unacceptable; (35-70%) is considered insufficient, and greater than 70% is sufficient to respond during an emergency. From analysis, we found that DMCH shows an unacceptable level of preparedness for a large earthquake disaster, as the total score is only 42 (Fig. 8).

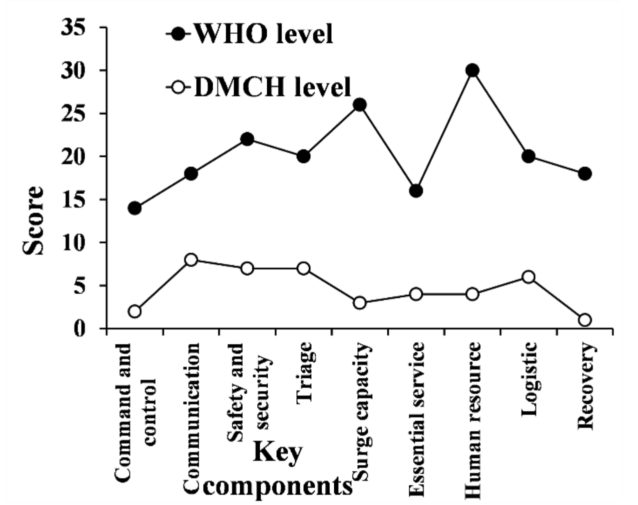


Figure 8: DMCH Score for Every Key Component. It Shows that DMCH's Scores for Every Key Component are Much Lower than the WHO Standard for a Hospital's Emergency Response. The Total Score for DMCH is 42 and, Hence, is at an Unacceptable Level of Preparedness.

Table 5: Percentage of Saved Lives Considering the Worst-case Scenario

Worst Case					
Number of Casualties	Need OT (D)	Capacity (C)	D/C Ratio of DMCH	Total number of saved lives	Percentage of saved lives
200	106	350	0.302857	102	96.22641509
500	265	350	0.757143	185	69.81132075
1000	530	350	1.514286	204	38.49056604
2000	1060	350	3.028571	204	19.24528302

Table 6: Percentage of Saved Lives Considering the Best-case Scenario

Best Case					
Number of Casualties	Need OT (D)	Capacity (C)	D/C Ratio of DMCH	Total number of saved lives	Percentage of saved lives
200	106	490	0.216327	104	98.11321
500	265	490	0.540816	226	85.28302
1000	530	490	1.081633	251	47.35849
2000	1060	490	2.163265	251	23.67925

Based on the proposed model, when the casualties increase from 200 to 1000, which is typical after a large earthquake disaster, for a tertiary-level hospital, like DMCH, the percentage of lives saved drops to 38.49% (worst case) and 47.35% (best case) and the hospital's preparedness is insufficient in both cases. Finally, when casualties reach 2000 or above, DMCH demonstrates an unsatisfactory level of preparedness, which is unacceptably low for a hospital like DMCH.

For all hazards, WHO's tool shows demonstrate unacceptably low preparedness for DMCH. The proposed model, as expected, shows sufficient preparedness for a smaller number of casualties and an unacceptable level of preparedness for a higher number of casualties which demonstrates the dynamic behavior.

Result and Discussion

This section discusses the analytical model's outputs considering DMCH as a case study. In addition, a dynamic range of results has been discovered, which is one of the key reasons for designing this model and distinguishes it from other methods. The outputs from different scenarios will help prioritize the treatment of various injured individuals.

As we mentioned earlier, assessing different levels of preparedness is possible based on the proposed analytical model for various numbers of victims and earthquake magnitudes. We have not assessed the DMCH structural vulnerability due to a lack of data and the limitations of research extent. However, it is necessary to conduct a complete structural vulnerability analysis to assess both structural and functional preparation. To estimate the level of preparedness, vulnerability analysis is needed as many hospital structures can be destroyed after an earthquake, and patients must be transferred to other hospitals right after (Ceferino et al., 2020, Mulyasari et al., 2013). If the result of a proper vulnerability assessment shows more than 30-35 percent damage, the authority must either retrofit the structure to avoid failure or rebuild it or take other required steps to avoid failure and prepare it. For simplicity and a lack of data, we have considered that DMCH hospital will be functional after an earthquake disaster (Grade 0 and 1 damages). However, proper vulnerability assessment is required for DMCH. It should be mentioned here that the proposed model is developed only for Grade 0 and 1 damage.

Case Study

A case study was considered using data from one of Dhaka's tertiary level hospitals (DMCH), with a bed capacity of 2600, to develop and demonstrate the proposed analytical model. It also features 35 OTs that can operate at any time for surgery purposes, as well as a number of medical personnel to support the OT and the outdoor section. According to the survey, during a normal day, almost 200 surgeries (large and small) take place at DMCH. It can accommodate a large number of patients daily. We have chosen this institution because of its vital significance in the healthcare industry of Bangladesh.

However, it is crucial to know whether it will be able to serve in case of a massive number of casualties following a disastrous earthquake. The most challenging part of earthquake emergency response is casualty management, as there is a negative correlation between treatment time and mortality rate. We have conducted a questionnaire survey to collect data on DMCH resources. From the analysis (output from the proposed model), figure 9 and figure 10 shows that this hospital is well prepared for a lower number of casualties. However, when the number of casualties increases, it shows an unacceptable level of functional preparedness. Therefore, the situation is inadequate as this hospital will receive the highest number of casualties in case of a catastrophic event.

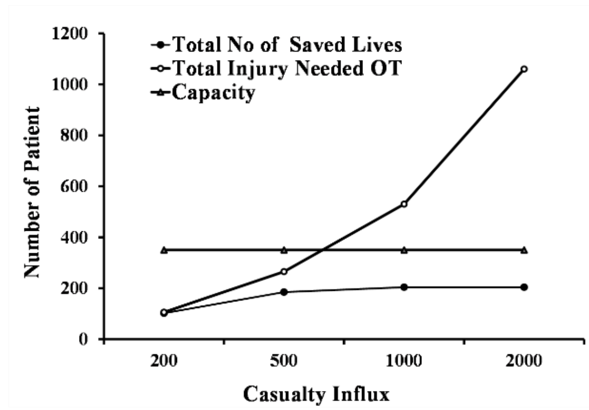


Figure 9: Total Injury Number Who Need OT Support and the Capacity of the Hospital (Worst Case Scenario). When the Injury Number is Small, It Shows Better Preparedness, and the Difference between the Total Injury Number and the Number of Saved Lives is Almost Similar. However, With the Increasing Number of Casualties, Preparedness Levels Start to Decrease

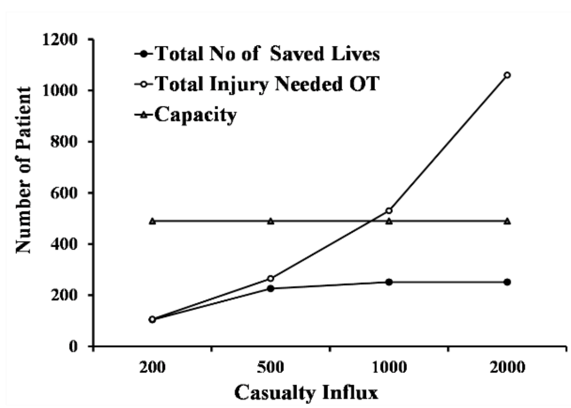


Figure 10: Total Number of Injured People Who Need OT Support and the Capacity of the Hospital (Best case Scenario). For 200 and 500 Casualty Influx, Hospital Preparedness is Acceptable. But in the Case of a 1000 Casualty Influx, the Demand Exceeds the Capacity. And, for 2000 Incoming Patients, the Preparedness Level is Unacceptable

In summary, as expected, it can be concluded that a hospital may have inadequate preparedness for a catastrophic event with a large number of casualties, although it may have adequate preparedness for a smaller-scale crisis with fewer casualties. This analytical model's dynamic character distinguishes it from other tools that are designed to assess preparedness.

Prioritize Casualties To Give Treatment

The primary goal of emergency medical services is to save more lives. Prioritization of casualty treatment should be in place to achieve this goal. After a catastrophic earthquake event, hospitals receive a large number of injured casualties with different types and levels of injury. Medical personnel must prioritize injured casualties to maximize the number of saved lives. To avail a clear understanding, three cases have been considered: the first case is severely injured people (11%) receive treatment first, followed by moderately injured people (23%); the second case is moderately injured people receive treatment first, followed by severely injured victims; and the third case is that severely and moderately injured people receive treatment at the same time, means half unit give treatment to the severely injured patients, and half will serve the others.

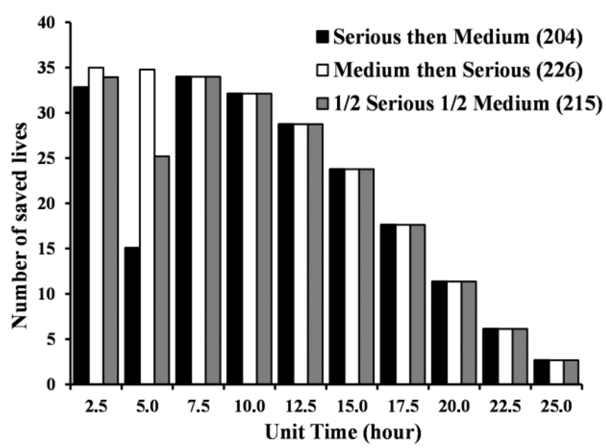


Figure 11: The number of Saved Lives Every 2.5 Hours for the Worst-case Scenario Where the Total Number of Saved Lives are 204, 226, and 215 for "Serious then Medium", "Medium then Serious", and "1/2 Serious 1/2 Medium" Treatment Priority Cases, Respectively

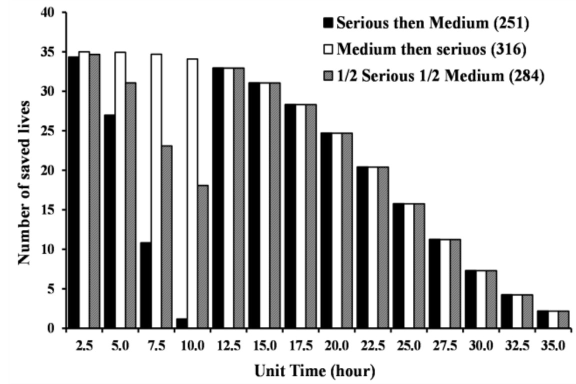


Figure 12: The Number of Saved Lives Every 2.5 Hours for the Best-case Scenario Where the Total Number of Saved Lives are 251, 316, and 284 for "Serious then Medium", "Medium then Serious", and "1/2 Serious 1/2 Medium" Treatment Priority Cases, Respectively

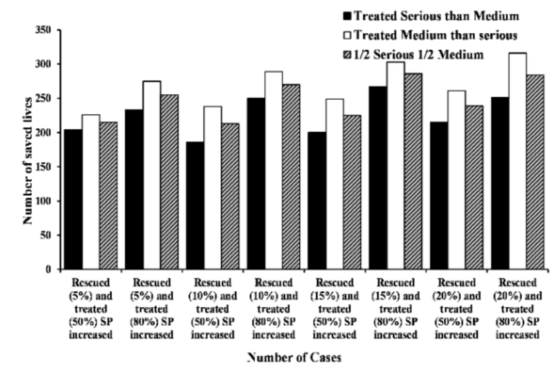


Figure 13: Number of Saved Lives for 2000 Casualty Influx Considering DMCH Existing Resources and Facilities. For Every Scenario, the Number of Saved Lives is Highest when Medium Casualties are Treated First

From figure 11 (worst case), 12 (best case), and 13, it can be clearly said that due to the high survival probability of medium injured victims if they get treatment from the beginning, the number of saved lives will be higher. However, it is impossible to say which level of injured casualties will come first to the hospitals. Therefore, if we consider that both types of injured casualties come to the hospital simultaneously, to maximize the number of saved lives, medical staff should treat the casualties with the highest chance of survival. (Chu and Zhong, 2015) also found that a support medical team should be assigned to a worse and more nearby affected area first in order to save more lives. The team may also be sent to a location of moderate severity and reasonable distance if the worst place is not the closest (Chu and Zhong, 2015)

There were some uncertainties, as we have considered simplified assumptions of casualty number and types, casualty influx and treatment, structural damages, resources efficiency, etc., in estimating the hospital preparedness by using the proposed simplified analytical model. Nevertheless, the proposed model will provide an understanding of the relationship between casualty influx and hospital preparedness level for earthquake emergency response. Therefore, the results of this study should not be used to prepare an earthquake emergency response plan but rather to give an idea of the level of hospital preparedness.

CONCLUSIONS

In this study, a simple analytical model was proposed to assess hospital preparedness for earthquake emergency response. The model was verified with the 'Hospital emergency response checklist' developed by WHO. The proposed model shows dynamic results for different numbers of casualties as well as different levels of preparedness, which cannot be seen in most of the existing methods for evaluating hospitals' preparedness. For this reason, this model could play a vital role for planners and policymakers in anticipating the impact of many possible earthquake scenarios on healthcare systems. From the outputs of different scenarios, they can formulate and evaluate alternative plans. It will ensure a high degree of preparedness to respond quickly and save more lives. This proposed model is considered simplified assumptions of the number of casualties and types, casualty influx and treatment, structural damages, resource efficiency, and rapid information. In order to get a more accurate result, our future considerations will include different arrival times for different levels of injured casualties at the hospital, randomness in the casualties' treatment time, human resources constraints, and randomness in the structural damages within the proposed analytical model. In addition, proper network analysis can be incorporated into the model to gain a better notion of the number of casualties arriving at the hospital. If possible, structural failure, soil liquefaction, debris obstruction, and other factors can be considered so that the administrative staff can estimate the expected number of casualties and plan accordingly.

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