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Hospital Patient Distribution After Earthquake

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***Abstract*—The correct organization of medical assistance after the occurrence of a major disaster is very important for saving the lives of the victims. Earthquakes are natural phenomena/disasters in which there are many victims. The timely provision of medical assistance to the injured is an important element of their service. It is good to divide them into types of injuries and severity of injuries. Thus, the medical teams will be prepared for how many people need outpatient treatment and how many need hospital treatment. Rapid distribution of victims to hospitals according to their injuries can reduce the number of deaths and people with serious consequences. In this article, we present a breakdown of the injured by hospitals and medical facilities near the earthquake site. The type of injuries and the capacity and equipment of hospital facilities are taken into account.**

***Index Terms*—Patient flow optimization, Earthquake, Distribution to hospitals**

I. Introduction

When a disaster situation occurs, such as a strong earthquake, the organization of medical assistance is of great importance for the rescue of the victims. The availability of information about the hospitals in the area, their equipment and capacity can be used for distribution of the injured. Their ability to provide adequate assistance to the wounded should be known in advance [1]. Earthquake zone maps exist for some areas. They are based on statistical and geological data and give the probability of an earthquake with a large magnitude [2]. The occurrence of a disaster situation is something of an emergency for hospitals, and for this there must be advance arrangements for the reception of victims of a certain type. The preliminary organization is to predict, calculate what number of victims there would be and of what type, knowing the type of construction, the occupants of each building and the type of heating they use. Two types of assessments can be made, one for the heating season and one outside the heating season. During the heating season, the likelihood of fires and people with burns is much greater than outside the heating season [3]. In the event of a disaster, hospitals must very quickly reorganize their organization for receiving and handling incoming patients, because they will receive a much larger number of patients than usually a certain type of patient. This is called the hospital's ability to respond and is determined by the hospital's normal capacity and the ability to expand [4].

$$RespondCapability = Planning \times Capacity$$

where the $Plannin$ is how much the capacity can be expended. Planning shows what the health facility's potential is if it uses all its available resources, such as staff, equipment, supplies.

The need for disaster medical preparedness planning and timely response was clearly seen in the corona virus pandemic [5]. This includes various components such as space, infrastructure, staff (medical and non-medical), medical and non-medical equipment. Although essential, planning and preparing for disaster response is often neglected. The reason may be the heavy workload with the daily sick [6].

The World Health Organization gives prescriptions for action in various disaster and pandemic situations, but they are too general and rather advisory, which makes it difficult to apply them directly [7]. The United States and the European Union also have developed prescriptions and disaster response plans. In some European countries, emergency departments are required by law to implement these prescriptions and plans, but they are also too general [8]. These are rather action plans for a particularly large flow of patients and are not entirely related to the disaster situation.

Giving first aid to the injured at the scene of the disaster, classifying them according to types of injuries and their severity, sending the seriously injured to hospital facilities is of great importance. This requires prior organization and material preparation, which is complex and should not be underestimated.

Therefore, mathematical models are made to be able to assess the disaster situation, the number and types of victims and what kind of help they need. A model is needed to be able to assess the specific situation and propose a solution for the disaster area. Thus, in different regions, the situation and the decisions to be taken will be different, tailored to the specific situation. This development aims to optimize the distribution of earthquake victims by hospital. Good organization helps to save lives, reduce and even prevent panic among the population.

The rest of the paper is organized as follows. Section 2 is devoted to literature review. Section 3 provides an assessment of the victims by type and number. In Section 4, an algorithm for the distribution of the injured by hospital facilities is presented. Section 5 provides a conclusion and direction for future research.

II. Literature Review

Advance planning, procurement and overall organization of rescue activities and medical care after an earthquake is extremely important to save people and prevent further consequences. This can be achieved by creating models showing the types of damage that would occur and the potential casualties. The types of construction in the considered region, the occupants of the individual buildings, the health facilities near the area of destruction and their capabilities, the expected magnitude of the possible earthquake can serve as input data. As a result, such models can show the type and number of victims, the medical assistance they need, the distribution of victims by health facilities, the necessary minimum of medicines and sanitary material that hospitals in the area must maintain.

Most of the existing models are aimed at rapid reconstruction of a hospital facility in case of a strong increase in the flow of patients, many times greater than normal [9]. A disadvantage of this approach is that it requires too much time and often lacks realism [10]. There are smaller patterns of patient flow that apply to specific departments in the hospital [11]. Other models are more comprehensive and consider the hospital and the flow of all patients as a whole [12]. These models are too general and do not reflect the reason for the increased admission of patients and their specificity.

There are models that are tailored to the disaster event, but again they are geared towards handling the increased number of patients. A model is proposed in [13] relating to increased patient flow due to an influenza epidemic. In [14], the model refers to patient care after a major fire, but again it is a single hospital. In [15], the model is for patient flow after an explosion.

Our proposed model targets patients at the scene of the disaster. First, an assessment is made of the possible victims and how many of them need hospital treatment. Hospital capacity information is used, starting with the nearest, until all those in need are served. The other models are primarily aimed at serving the growing number of patients.

III. Assessment of Patients

There are a variety of models for assessing earthquake victims. The devastating earthquake consequences for the environment are a major cause for the occurrence of numerous medical emergencies. There are usually large numbers of permanent (deaths) and temporary (injured) medical losses. The types of injuries are diverse in type and structure. The direct impact trauma factor is the most common in cases of earthquake, as the direct impact is usually caused by airborne debris and falling objects from demolishing buildings, thus inflicting mostly traumatic injuries - see Clark (2018) [16]. In cases of secondary disaster area occurrences, it is possible to have impact factors like radiation; toxic substance release; thermal impact, biological impact, etc., which can cause radiation damage; acute poisonings; thermal injuries; outbreaks of infectious diseases; cases of drowning. The negative effects of the psychological stress factor are inevitable and they cause acute neuropsychological conditions in vast numbers of people - see Farooqui et al. (2017) [17], Todorova et al. (2020) [18], Etova (2021) [19].

In Tirkolaee et al. (2020) [20] a robust bi-objective mixed-integer linear programming model to allocate disaster rescue units is proposed. The authors apply the model to a real case study for Mazandaran province in Iran. The same problem for resource allocation for emergency response is studied in Fiedrich et al. (2000) [21]. They develop dynamic optimization model and a method for solving it. The goal is to present a schedule for optimizing of the available technical resources. Robust Model for Logistics Management (RMLM) is proposed in Najafi et al. (2012) [22]. The model is multi-objective, multi-mode, multi-commodity, and multi-period. It is proposed to manage the logistics of commodities and injured people in the case of earthquake. A three objective mixed integer stochastic model for locations of storage areas for shelters pre-earthquake and distribution of shelters is proposed in Yenice and Samanlioglu (2020) [23]. The authors consider four event scenarios according to two different earthquake scenario likelihoods. The model was applied to Kadikoy municipality of Istanbul, Turkey. Dawei et al. (2015) [24] the problem about vehicle scheduling in the medicine dispatching process is studied in order to minimize the total transportation time under several types of vehicles. The problem is solved by genetic algorithm.

Transient modelling with quadratic regression analysis for simulation of hospital operations in emergency situations is studied in Paul et al. (2006) [25]. A double exponential function is used to model the transient waiting time. De Boer and Debacker (2006) [26] determine the medical resources for disasters in the Netherlands. They study the medical rescue capacity, the medical transport capacity and the hospital treatment capacity using medical severity index model. Several cases are considered under different assumptions of severity. A stochastic Petri net is used for modelling and optimizing the emergency medical rescue (EMR) process in Sun et al. (2021) [27]. The approach is tested with the data of the 2008 Wenchuan earthquake. Ghasemi et al. (2020) [28] propose a stochastic multi-objective mixed-integer model for logistic distribution and evacuation planning during an earthquake. The model is converted into deterministic one and then solved by means of genetic algorithm NSGA-II. The model is tested for a probable earthquake in Tehran.

In [3] is proposed a model, bazed on Generalized Nets, for processes occurring during an earthquake. With the help of this model, damage and casualties can be estimated when we know the types of construction, its earthquake resistance, the number of occupants of each building and the type of heating.

The injured will be divided into lightly injured and severely injured. Minor injuries can receive medical attention on the spot and do not require hospitalization. The seriously injured are people who will receive first aid on the spot and then be directed to hospital treatment. We divide the severely injured into two main groups. Victims with fractures and victims with burns.

Let the number of residents of a given building be N. If the earthquake resistance of the building is less than the strength of the earthquake, then there will be major damage to the building and we assume that the number of occupants with fractures will be F, where:

$$F = 0.25 * N$$

If solid fuel heating is used in this building, local fires are likely to occur and the number of people with burns will be B, where:

$$B = 0.1 * N$$

In case of strong earthquakes with a magnitude above 7, if there is a gas installation in the building, there is a high probability of damage to the installation and gas leakage. This could result in a serious fire and people with severe burns. In this case, we assume that people with severe burns will be B, where:

$$B = 0.5 * N$$

All these victims need hospital treatment. Of course, in the preparation of the emergency teams, people with minor injuries and minor burns, who will not need hospital treatment, but sanitary materials will be used for them, should also be taken into account. For people with serious injuries, sanitary materials will also be used in providing first aid on the spot before being taken to a hospital facility. The percentage of casualties out of the total number of occupants was determined in consultation with disaster medicine specialists. These percentages are input parameters to the model and can be changed and refined.

IV. Patient Distribution to Hospitals

The model of the consequences of an earthquake, which we have done in our previous development, estimates the types of damage from a given area [3]. They are grouped into two types of injuries, fractures and burns. Each type has two main subtypes, heavy and light. Severe ones require hospital treatment, while mild ones can be treated on site and patients referred to accommodation centers. Of interest to this article are the victims who need hospital treatment and their distribution by hospital.

Let there be n number of hospitals within a radius of 50 km from the epicenter of the earthquake $\{H_1, H_2, H_3, \ldots, H_n\}$, where H_1 is the closest hospital to the epicenter and H_n is the most distant hospital to the epicenter. For each hospital, there is a vector with information about it.

$$H_i = (d_i, cf_i, cf1_i, cb_i, cb1_i)$$

where d_i is a distance from the earthquake epicenter to the hospital, cf_i is the capacity of the trauma department and $cf1_i$ is the capacity of possible extension of trauma department; cb_i is the capacity of the hospital's burn department and $cb1_i$ is the possible extension of the burn department.

If the hospitals within a radius of 50 km do not have sufficient capacity (including extended capacity) to accommodate the expected number of victims, new hospitals are added, increasing the radius by 10 km. We increase the radius until enough hospitals are involved to accommodate all the seriously injured.

Some of the smaller hospitals only have a trauma unit and no burn unit. Then the value for the capacity of the burn unit is $cb_i = 0$ and for extension of the burn unit is $cb1_i = 0$.

When drawing up a plan for the distribution of injured people, it is first assessed which of the available hospitals have an earthquake resistance equal to or greater than the magnitude of the expected earthquake. This means that the hospital will not have significant damage and will be able to function. If the earthquake resistance of the hospital building is less, then we set its capacity to be $cf_i = 0$, $cf1_i = 0$, $cb_i = 0$ and $cb1_i = 0$. Thus, this hospital will not enter the casualty distribution plans. The goal is that the total time for accommodation of the victims is minimal.

We offer the following algorithm for the distribution of the injured by hospitals:

1 The victims are distributed according to the severity of the injury;
2 $i = 1$;
3 If $cf_i > 0$ $vf_i = min\{cf_i, F\}$; The distribution of fracture victims starts from the closest hospital to the epicenter with capacity $cf_i > 0$, vf_i are fracture victims distributed to H_i, F are not distributed fracture victims;
4 After the places are filled, this hospital is removed from the list by placing $cf_i = 0$;
5 $F = F - vf_i$;
6 $i = i + 1$;

7 If $i <= n$ and there are unallocated casualties ($F > 0$), return to position 3;
8 If $i > n$ and $F > 0$, return to position 2 using $cf1_i$ instead of cf_i, otherwise we move to position 9;
9 All the injured have been transferred to appropriate hospitals.

A similar scheme is also used for the distribution of victims with severe burns.

The radius of the hospitals in which victims with fractures are distributed may be different from the radius of hospitals in which the victims with severe burns are distributed. This is because, on the one hand, the victims of earthquake with fractures, especially outside the heating season, are much more than the victims with burns. On the other hand, most hospitals for general treatment, including small ones, have trauma departments. This is not the case with burn departments.

When determining the capacity of a department, the possibility of placing additional beds and serving additional sick/injured patients is also taken into account. The additional beds/casualties represent additional overburdening of the hospital and, from there, a possible decrease in the quality of the service. Additional beds are filled when all hospitals in the area are at capacity and there are unserved casualties. The same algorithm is applied for extensions of the hospitals. In the proposed algorithm, a balance is sought between the time to take the patients to a hospital and the quality of the health service offered.

V. Computational examples

We have prepared the following example to show how our proposed algorithm works.

The example consists of residential region with: 8 high apartment buildings with 210 inhabitants each; 42 apartment buildings up to 3 floors with 36 inhabitants each and 500 family houses with 4 inhabitants each. The number of all inhabitants of the region is 5192. There are various types of heating.

Let there be one hospital in the settlement. This hospital has a trauma department with a capacity of 50 beds and can be expanded to 150 beds. The hospital does not have a burn unit. At a distance of 10 km there is a hospital with a trauma department with a capacity of 100 beds and the possibility of expansion to 300, as well as a burn unit with a capacity of 10 beds and the possibility of expansion to 20. At a distance of 20 km. there is a hospital with a trauma department with a capacity of 50 beds, expandable to 200, without a burn department. At a distance of 30 km. there is a hospital with a trauma department with a capacity of 300 beds, expandable to 800, and a burn unit with a capacity of 20 beds, expandable to 80.

When the magnitude of the earthquake is up to 7 there will be no died people. The people with minor injures will be 463, with fractures they will be 200 and 40 with minor burns, because some of the houses use solid fuel heating and it can cause local fires.

In this case, there are 200 people with fractures, 50 of them will be admitted to the first hospital, 100 people will be admitted to the hospital 10 km away and the remaining 50 will be admitted to the extra beds in the first hospital. No one suffered serious burns, only minor burns were reported and they could be treated at the scene by paramedics or emergency responders.

When the magnitude of the earthquake is 8 and more there will be 689 died people. The people with minor injures will be 1919, with fractures they will be 1246. There is a possibility for explosion of gas installation, therefore there will be 15 peoples with hard burns and 206 with minor burns.

In this case, there are 1,246 people with fractures. 50 of them will be accommodated in the first hospital. In the hospital 10 km away, 100 people will be accommodated. In the hospital 20 km away, 50 people will be accommodated and 300 people will be accommodated in the hospital 30 km away.

The remaining 646 people will be accommodated on the extra beds as follows. 150 people will be accommodated in the first hospital. In the hospital 10 km away, 300 people will be accommodated. The remaining 196 people will be accommodated in the hospital 20 km away. In the hospital 30 km away, no additional beds will be accommodated.

We have 15 victims with severe burns who need hospital treatment. There are burn departments in the hospital 10 km away and in the hospital 30 km away. The hospital 10 km away has a capacity of 10 beds with the possibility of expansion by another 20. All burn victims will be taken to this hospital because the number of victims exceeds the normal capacity of the hospital by only 5 people and the expanded capacity is not exceeded.

VI. Conclusion

In this article, we have proposed a model for the distribution of earthquake victims in hospital facilities. The type and number of victims, the equipment of the hospitals and their capacity, their ability to reorganize their activities were taken into account. The distance of the hospital to the scene of the accident was also taken into account. Patients are sent to the nearest possible hospital that can provide them with the necessary care until its capacity is filled. The goal is to optimize medical care.

The purpose of the model is a preliminary assessment of the injured and their need for medical care. On the basis of this assessment, a preliminary plan can be drawn up for the distribution of the injured by hospitals and medical centers.The model can serve for the training and preparation of medical teams, as well as for the material security of hospitals.

As future work, the model will be further developed and refined. On its basis, models could be created for medical assistance in other types of disaster situations.

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