

# Optimal Earthquake Victim Assistance

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**Abstract**—Strong earthquakes can cause many deaths and injuries. In order to reduce casualties, preliminary organization must be created. For this purpose, people are divided into groups by type and severity of injury, and by probability of survival. The plan includes information on the health status of the patients, the personal medical staff and their qualifications, as well as the number of paramedics who can be included. The goal is to create appropriate response plans and train people in advance. This can reduce casualties and help to address survivors' problems more quickly. In our development, we use a combination of cluster analysis and optimization algorithms to guide victims to medical aid points.

**Index Terms**—Patient flow optimization, Cluster analysis, Distribution to hospitals.

## I. INTRODUCTION

LARGE natural disasters such as earthquakes, volcanic eruptions, typhoons, and floods cause not only self-destruction and large material losses, but also many deaths and injuries. To assist the victims and provide assistance to the injured, local and medical authorities must be well prepared. The preparation and response plans depend on the natural environment. These should be adapted to local conditions. In this study, we focused on assessing and assisting earthquake victims. It is important to have preliminary data on the medical capabilities of the area. It is necessary to know in advance what medical teams will be available on the ground. These teams include paramedics and nurses, who will assess and provide first aid to the injured.

We need the information about hospitals within a radius of at least 50 km. There are two types of information: what the earthquake resistance of the hospital building is and to assess whether the system would be able to provide services in the event of an earthquake of a given level. Another necessary information is what services the hospital offers. This includes what departments it has, what equipment it has, what specialists it has. There are well-equipped hospitals that could have treated patients with these injuries, while there

are hospitals that are designed to treat minor injuries. Some hospitals do not have a burn department [1].

When creating a prescription for earthquake response, statistical and geological data are used, on the basis of which the probability of an earthquake of a given magnitude is calculated [2]. Preliminary preparation is done based on these data and assessments. The following is a list of victims, including the number and type of injuries. There is a difference whether the earthquake occurred during the heating season or outside it. When the earthquake occurred during the heating season, the probability of a fire is much higher. This leads to more victims with burns [3]. When a disaster occurs, including an earthquake, hospitals in the disaster area go into emergency mode. This leads to a reorganization of the affected wards due to the strong increase in patients in them, much above normal. The ability of a hospital to accept more patients than usual is called expanded capacity [4]. The ability of a specific hospital to respond and admit additional patients is determined by the following formula:

$$RespondCapability = Planning \times Capacity$$

where the *Planning* is the possibility of expansion, how much the reception of victims can increase. All of this depends on the possibility of placing extra beds, the available equipment and the supply of additional, available staff.

The need for advance planning and preparation for the emergence of a critical situation was clearly seen during the coronavirus pandemic [5]. It is established that preparation for an emergency situation, such as a bedridden patient, is often neglected. The reason for this is the high workload and lack of time [6]. The World Health Organization provides general guidelines for responding to disasters. These can serve as a basis for developing models and plans for specific situations and locations, but are often neglected because they cannot be directly applied and are not actionable [7]. The European

system has a response plan for disaster, but it is too vague and unwieldy to be directly applied. It is necessary to present a response plan for an increased number of patients sooner, without any connection to the specific situation and location [8]. This was the case during the coronavirus pandemic.

The aim of this work is to propose a model for assessing victims and allocating them for medical care. The assessment is carried out in several stages. This distributes victims in the clusters according to their probability of survival, injury type and type of emergency, requiring hospital treatment. It is included in the algorithm for distributing patients within the hospital. In a hospital, there is only one stage for assessment and distribution to hospital departments. The aim is to provide quick and efficient medical care.

The paper is organized in a following way. Literature review is given in section II. Section III provides pre-hospital triage of the injured. It is carried out in 2 stages. Section IV presents an algorithm for hospital distribution and intra-hospital triage of victims. A computational example is given in Section V. Section VI is summarizing and provides directions for further development of the research.

## II. LITERATURE REVIEW

Advance preparation and training of medical personnel are essential for the survival of earthquake victims. In strong earthquakes, there are many casualties and the need for hospital treatment is several times greater than usual. When we have a plan for the consequences of an earthquake, we can make a preliminary assessment of the victims, grouping them by age and condition. This allows us to plan for the expansion of the relevant departments in the hospital, including the temporary transformation into a department for the care of the victims.

Some of the existing models emphasize the reorganization of hospitals to accommodate the increased flow of patients [9]–[11]. A disadvantage of these models is that they require too much time, which we do not have available when the event occurs. Other models are too general and do not take into account the specifics of patients [12].

There are models that focus on the distribution and care of patients who have already arrived at the hospital. This does not mean that the hospital will not be able to handle the medical treatment at the scene of the incident. Similar models are seen in [13] for influenza epidemics, models in [14] for deaths from cooking fires, or models in [15] for deaths from explosions.

Different types of disasters lead to different types of trauma. For this reason, it is not possible to use both models, but separate models should be developed for different disasters, in order to be able to take into account their specificities. In earthquakes, injuries are mainly caused by a falling object or the collapse of a building, by impact from a fall, or by burns in the event of a fire [16]. Due to the earthquake, additional accidents may occur that could cause the release of toxic gas, radiation, biological contaminants, etc. Increased stress can cause difficult-to-predict psychological deviations in people with a more labile psyche [17]–[19].

In [20] a model for the distribution of medical points has been proposed using bi-objective mixed-integer linear programming. The model was applied to an earthquake in Iran. A model for distributing emergency medical teams is also discussed in [21]. The model is based on dynamic optimization. In [22] is proposed multi-objective logistic management model for management logistics of injured people in earthquake. Algorithm for optimal location of shelters is proposed in [23]. The model was apply in real situation in Turkey. Minimizing the time for delivering medicines and dressings is described in [24]. To solve the problem, genetic algorithm is applied. Hospital operations in emergency situations are modeled applying quadratic regression analysis in [25]. The medical resources for disaster situations are appreciated in [26]. Resource capacity, transport capacity and hospital capacity are taken in to account.

Emergency medical rescue process is modeled and optimized in [27]. The model is tested on real data from Wenchuan earthquake from 2008. Logistic distribution and evacuation planning is proposed in [28] using stochastic multi-objective mixed-integer programming. The algorithm is realized by genetic algorithm NSGA-II. The model is tested for the region of Tehran.

Processes occurring during the earthquake are modeled with the help of Generalized Nets in [3]. The model appreciates damages and casualties in accordance of type of building earthquake resistance, heating type and number of occupants.

## III. ASSESSMENT OF VICTIMS

For optimal assessment and assistance to earthquake victims, we will use a three-stage triage. It will be implemented with the application of cluster analysis.

In the first step of triage, victims are divided into two groups: people with a chance of survival and people with no chance of survival. This separation is carried out at the site of the destruction. Victims with no chance of survival are offered means to alleviate suffering. This is done at the place of the accident or the victims are moved at the appropriate place. This activity can be performed by medical personnel or paramedics.

People in the second cluster go through the second level of triage. These are people with different types and degrees of injuries. They are again divided into two clusters: victims with minor injuries and abrasions and victims requiring hospital treatment. The assessment and distribution is carried out by a medical professional or paramedic. People with minor injuries who do not require hospital treatment will be treated at mobile medical stations.

Injured people who require hospital treatment are subject to the third degree of triage. It is performed by a doctor. In this case, we have several clusters according to the types of injuries, with each cluster having subclusters according to the severity of the injury. We consider the following three main groups of injuries: fractures; burns and head injuries. Generally, people with fractures injuries will be referred to the trauma department, people with burns will be referred

to the post-burn department; people with head injuries will be referred to the neurology department. Each of these three clusters consists of sub-clusters, depending on the severity of the injury and the type of treatment to be administered.

The subcategories of cluster (1), fractures, are as follows:

- 1.1 breakage without displacement;
- 1.2 breakage with displacement without open wound;
- 1.3 breakage with open wound.

In the case of cluster (1.1) the patient is only required to be plastered or splinted, as there is no need for surgical intervention. The degree of urgency is low. In the case of cluster (1.2), surgical intervention is required. The degree of urgency is medium. In the case of open wound (1.3), the victim needs surgical treatment. The degree of urgency is high.

The subcategories of cluster (2), burns, are as follows:

- 2.1 Type 1 burn, affects only the epidermis, outpatient treatment;
- 2.2 Type 2a burn, affects the dermis on a small area, no risk of infection, outpatient treatment;
- 2.3 Type 2b burn, affects only the dermis, but is on a large area, there is a risk of infection, hospital treatment without the need for surgery;
- 2.4 Type 3 burn, reaches the blood vessels, there is necrotic tissue, surgery is required;
- 2.5 Type 4 burn, reaches the muscle tissue, requires surgery.

The subcategories of cluster (3), head injuries, are as follows:

- 3.1 Head trauma without fractures, requiring hospital treatment without surgery;
- 3.2 Trauma with skull fracture, surgical treatment.

Different types of trauma require different types of hospital care and equipment. For example, patients from class (3.1) may be distributed to a hospital with a neurological department that does not have a neurosurgery. While patients from cluster (3.2) should be sent to a hospital with neurosurgery.

People from different clusters have different severity of injuries. Those with higher level of injury will have a higher coefficient and will be served before those with lower coefficients. If a patient has more than one injury, the most serious injury is treated first, and then the others in order of their severity.

#### IV. ALGORITHM FOR OPTIMAL HOSPITALS DISTRIBUTION

In our previous works [3], [29] we propose a model for estimation of injured after an earthquake and distribution to hospitals. We took into account only two types of injured, fractures and burns, and for every injury we grouped them into two subtypes, heavy and light. In this study, we look at three types of injuries: fractures, burns, and head injuries. For the fractures we divide patients on three types. For burns we divide patients on 5 types and for head traumas we divide patients on two types. We combine clustering and optimization. Thus this research is a continuation of previous ones [3], [29], [30].

In the second level of triage, victims are divided into two groups: treatment of injuries on site; need for hospital treatment. Non-displaced fractures requiring splinting or casting

can be treated on site. Type 1 and 2a burns can also be treated on site and do not require hospital treatment. This type of medical care is provided by mobile teams or temporary medical stations. It is not life-threatening and does not have a high level of urgency.

The remaining injured require hospital treatment. The capacity of hospitals in the area should be known, as well as their expansion possibilities. In addition to increasing beds in the relevant departments, rooms, equipment and staff from other departments can be used for some of the cases. For example, with a type 2b burn, there is a risk of infection and therefore treatment must take place in a hospital, but surgery is not necessary. After the injured area is treated, the patient can be transferred to another appropriate ward. This will free up space in the burn ward for severely injured patients with type 3 and 4 burns, whose treatment requires specialized care and equipment.

Each hospital is required to provide information about the types of departments it has and the types of services it offers. For example, a hospital may have a neurological department but no neurosurgery. This means that only people with head injuries who do not require surgical treatment may be referred there. Each hospital is required to provide information about the types of departments it has and the types of services it offers. For example, a hospital may have a neurology department but no neurosurgery. This means that only people with head injuries that do not require surgical treatment can be referred there. Similarly, type 2b burns require inpatient treatment but do not require surgery, while type 3 and 4 burns require surgical treatment. When a patient has multiple injuries, they are assigned to the cluster with the most urgent injury, but when referring to a hospital, their other injuries should also be considered if they also require hospital treatment.

Another necessary information is the earthquake resistance of the hospital building. From this information, it can be assessed whether there are any damages to the building and how serious they are. If the hospital building is seriously damaged and cannot or is dangerous to use, it is removed from the list of hospitals and given a capacity of 0. Several lists of hospitals are being compiled. The first list includes hospitals within 50 km of the destruction. Victims can be transported to these hospitals within 1 hour, which is very important for emergencies. The second list contains the hospitals within a radius of 100 km. This is a reserve list that will be used in case the nearest hospitals are unable to accommodate all the injured. The reasons may be that there are too many injured or that the buildings of some of the nearby hospitals are severely damaged. A third list of specialized hospitals of national importance is also being compiled. These are hospitals with unique or highly specialized modern equipment. They may be located at a greater distance. Severe cases are sent there that cannot be treated in hospitals in the area.

The hospitals in the first two lists are ordered by distance, starting with the closest one. The information for each hospital is formatted as a vector:

$$H_i = (d_i, a_i, a1_i, b_i, b1_i, b2_i, c_i, c1, c2_i) \quad (1)$$

where  $H_i$  is a hospital  $i$ ;  $d_i$  is the distance from the destruction;  $a_i$  is the capacity of the trauma department;  $a1_i$  is the expanded capacity of the trauma department;  $b_i$  is the capacity of the burn department;  $b1_i$  is the expanded capacity of the burn department;  $b2_i$  is 1 if the department has a surgeon and 0 if it does not;  $c_i$  is the capacity of the neurology department;  $c1_i$  is the expanded capacity of the neurology department;  $c2_i$  is 1 if it has a neurosurgeon and 0 if it does not. If any of the hospitals have not some of the departments, the value for the capacity and extended capacity is set to be 0.

The victims with high level of urgency will be distributed to the hospitals with higher priority. The clusters with high priority are 1.3, 2.5, 3.2. The cluster with medium priority is 2.4. The clusters with low priority are 1.2, 2.3, 3.1.

If a patient has two injuries of different types, but both are high priority, then he is sent to a hospital that has both types of departments. For example, if a patient has a type 1.3 injury and a type 2.5 injury, then he should be taken to a hospital for which  $a_i + a1_i > 0$ ,  $b_i + b1_i > 0$  and  $b2_i = 1$ .

The information for each patient is represented as a vector  $P = (x1, x2, x3, y1, y2, y3, y4, y5, z1, z2)$ .  $x1$  corresponds to breakage without displacement;  $x2$  corresponds to breakage with displacement without open wound;  $x3$  corresponds to breakage with open wound.  $y1$  corresponds to type 1 burn;  $y2$  corresponds to type 2a burn;  $y3$  corresponds to type 2b burn;  $y4$  corresponds to type 3 burn;  $y5$  corresponds to type 4 burn.  $c1$  corresponds to head trauma without fractures;  $c2$  corresponds to trauma with skull fracture. In the absence of a given type of injury, the corresponding position in the victim vector has a value of 0. The more severe and urgent the injury, the greater the value of the respective position. When a casualty arrives at the hospital, they are first treated for the most serious and urgent injury, then the less serious injuries are treated. The positions in the patient vector that correspond to minor injuries not requiring hospital treatment can take values 1 or 0. This means whether or not they have such an injury. These are positions  $x1$ ,  $y1$ ,  $y2$ . Injury type 1.2, 2.3 and 3.1, positions  $x2$ ,  $y3$  and  $z1$  are of medium urgency. Injury 1.2 requires surgery, while injuries 2.3 and 3.1 do not require surgery, so we set their values 10 for 2.3 and 3.1, and 20 for 1.2 if the patient has such an injury. Injuries of type 1.3, 2.4, 2.5 and 3.2 are of high urgency. They correspond to positions  $x3$ ,  $y4$ ,  $y5$  and  $z2$  and have a value of 50 respectively. Thus, when value of the patient's vector position is greater than 10, surgical intervention is required and the patient should be sent to the appropriate department with a surgeon.

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

- 1 Patients for whom the sum of the values of the elements of their vector is more than 50 are distributed first.
- 2 It is checked whether they have more than one injury.
- 3 It checks which hospital is the closest from the first list with available places in the respective type of injury.

- 4 If the places from the normal capacity in the appropriate hospitals from the first list are filled, it is checked whether there are any free places from the expanded capacity. If there are no free places there either, it is checked in the second list.
- 5 After the patient is distributed to a hospital, its capacity/expanded capacity is reduced by one.
- 6 If there is a patient with severe injuries who cannot be admitted to an appropriate hospital from the first and second lists, he is admitted to a hospital from the third list.
- 7 The procedure is repeated until all victims have been treated appropriately.

This algorithm treats patients with high levels of urgency, for whom response time is life-saving, first. Hospital beds are filled starting from the normal capacity of the nearest hospital. Once the normal capacity of all hospitals on the first list is filled, the expanded capacity of the hospitals on the first list begins to be filled. When that is also filled, the distribution of patients to hospitals on the second list begins. Patients with severe injuries who cannot be treated by hospitals on the first and second lists are sent to a hospital on the third list.

The algorithm takes into account the urgency of the injury, i.e. the time frame within which the victim must be treated. Our goal is for victims to receive quality service in the shortest possible time.

## V. COMPUTATIONAL EXAMPLE

The following small example illustrates how the algorithm works.

Let the first list contain 3 hospitals with the following characteristics:

$$H_1 = (1, 10, 5, 0, 0, 0, 10, 2, 0)$$

$$H_2 = (10, 20, 5, 10, 2, 1, 10, 2, 0)$$

$$H_3 = (15, 20, 5, 10, 2, 1, 10, 2, 1)$$

We have the following types of victims:

$$P_1 = (0, 20, 0, 0, 0, 0, 0, 0, 10, 0)$$

$$P_2 = (0, 0, 0, 0, 0, 0, 0, 0, 0, 50)$$

$$P_3 = (1, 0, 0, 0, 0, 0, 50, 0, 0, 0)$$

$$P_4 = (0, 0, 50, 1, 0, 0, 0, 0, 0, 50)$$

We apply the proposed algorithm for distribution by hospital.

Patient  $P_1$  has a fracture without displacement and a head trauma without fracture. He will be transferred to hospital  $H_1$ , because there is a trauma department there, as well as a neurology department. There is no neurosurgery in  $H_1$ , but in this case it is not necessary.

Patient  $P_2$  has a head injury with a fracture. Surgical treatment is required. He will be distributed to hospital  $H_3$ , because of the nearby hospitals, only there is a neurosurgeon.

Patient  $P_3$  has burns of type 3 and requires surgical treatment and breakage without displacement. He will be distributed to hospital  $H_2$ , as there is burn department with surgery.

Patient  $P_4$  has a fracture with an open wound and a head trauma and a fracture to the skull. Surgical intervention is also being planned for the second injury. It will be distributed to hospital  $H_3$ , where there are also traumatologists and neurosurgeons.

## VI. CONCLUSION

Good organization of medical care can be crucial for rescuing earthquake victims. In this paper, we propose an algorithm for providing medical aid to victims. The algorithm is a combination of cluster analysis and optimization. First, three stages of triage of people are applied. This depends on their chance of survival and the degree of injuries. For those who need hospital treatment, an algorithm for optimal distribution to hospitals is proposed. The available wards, equipment and staff, bed capacity and expansion possibilities are taken into account. Distribution starts from the victims with a high level of urgency. The goal is to minimize the time for distribution to the hospital and to provide better medical care. The ultimate goal is to save human lives and recover the victims more quickly. This model will be used as a basis for creating models for assistance to victims in other disasters.

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