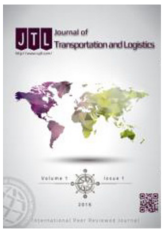

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RESEARCH ARTICLE

Post-Earthquake Casualty Transport Optimization

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ABSTRACT

Disasters are one of the deadliest problems faced by humans in their struggle to survive in nature throughout history. This study was carried out for the optimization of the casualty transport process after the earthquake, which is one of the most powerful disaster types today. This study, in which what needs to be done in the post-earthquake response phase is planned, it is aimed to design a logistics network that will ensure that the patients who survive the earthquake with severe injuries are treated as soon as possible. For the problem's resolution in this way, a two-stage solution model is recommended. The proposed mathematical model is first solved using a mixed integer programming approach. The outputs of the mathematical model were simulated using the new patient selection procedure in the second stage.

Thanks to the proposed model, it has been determined which ambulances to transport the patients to which hospital and preferences that will minimize the total time have been formed. Finally, the developed new mathematical model and patient selection method were tested with earthquake forecast data for the Tuzla District of Istanbul Province. After conducting a baseline study, the model's sensitivity to changes in parameters and constraints under various scenarios was assessed (scenario 2, scenario 3). Sensitivity analysis results showed improvements in total transport times with additional hospital setup and ambulance allocation.

Keywords: Casualty Transport, Disaster Logistics, Disaster Management, Earthquake Response, Logistics Network Design, Network Optimization, Mixed Integer Programming

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1. Introduction

Disasters are sudden, catastrophic events that exceed a region's ability to cope with based on its means, cause large-scale economic, social, and environmental losses, and disrupt the daily functioning of society. Although it is generally caused by nature, man-made disasters can also occur (IFRC, 2020).

Disaster and emergency logistics are systems that effectively deliver humanitarian aid, materials, food, medicine, and health services together with information and human resources, which disaster survivors need (Kadıoğlu, 2011).

Logistics activities are one of the most important factors in the implementation of humanitarian aid operations in disasters and emergencies.

An effective, dynamic, adaptive, and locally dependent network should be developed because the post-disaster reaction phase of disaster logistics is more time-critical than pre-disaster preparations (Altay, 2008). After major disasters such as earthquakes and floods, activities such as the evacuation of victims, transportation of casualties, and delivery of humanitarian aid require significant logistics distribution network design (Berkoune et al., 2012).

Natural/human-induced disasters that harm the social and economic order and hinder the progress of societies should be handled with all their dimensions. The causes of damage to society and the environment should be examined as a whole and solutions should be produced to reduce their effects (Sarp, 1999). In addition, it can be said that the need for operations research in the field of disaster logistics management has increased (Altay & Green, 2006).

One of the most important activities carried out during the response to natural disasters such as earthquakes is the logistics of transporting the injured after the disaster, which is included in the category of "medical first aid, treatment, and transport to hospital" (Deniz, 2012). Saving large numbers of human lives and meeting the basic humanitarian needs of disaster casualty is possible with good transportation planning.

The type of logistics activity discussed in this study is a network design for the logistics of injured people after the earthquake. It's crucial that logistics activities can proceed without incident in unpredictable circumstances like natural disasters, where uncertainty and unpredictability are widespread. Numerous metrics are abnormal both during and after a natural disaster, such as an earthquake, where many factors outside human control are at work. This study aims to design a logistics network that will ensure that the patients who survive the earthquake with severe injuries are treated as soon as possible. In this direction, a mathematical model for the solution was developed and a new patient selection strategy was proposed. This new model's study of the current situation (scenario 1) has been put to the test, and sensitivity analyses for scenarios 2 and 3 have been performed with the addition of new field hospitals and ambulances to the system. For this purpose, with mixed integer programming, it was determined which ambulances should transport the injured to which hospital, and the preferences that would minimize the total time were created.

In the event of an earthquake, ensuring that information such as requests for assistance, machinery and equipment inventory, capacity, and competence is transmitted accurately can save many lives. In a situation where the location, triage, and number information of the injured are determined correctly, maximum benefit can be obtained in directing the medical teams. In studies on post-earthquake interventions, it is of great importance to establish a model based on the realistic estimates of the relevant parameters and to simulate the model in terms of summarizing the picture that will be encountered after the disaster (Adrang et al., 2020).

The aim of this study is to design a network for transporting people who are rescued with serious injuries every hour to hospitals by ambulances in a way that minimizes the total time during the post-earthquake response phase. In each period, the number of service requests for the seriously injured varies, and hospital capacities are gradually decreasing. A two-stage solution model is proposed for this problem. The mathematical model proposed in the first stage is the mixed integer programming model. The second stage is the stage in which the outputs of the mathematical model are simulated on a period-by-period basis.

For the test of the proposed model, Tuzla District, which is in the 1st Group among the riskiest districts according to the risk map of Istanbul (Kaya, 2000), was selected. In the model, the estimation data of Tuzla District in the earthquake projections made for Istanbul Province and the hospital, ambulance, and location information of the district were used.

The first 72-hour period from the moment of the earthquake is critical to saving the lives of the injured (Öner, 2010; Tanrıöven, 2010). As the hours' progress, the probability of people surviving decreases. For these reasons, it was assumed in the study that people were rescued without injury during the 72 hours.

In the first of three different scenarios created, the model was run according to the existing hospital and ambulance capacity of the district. In the second and third scenarios, according to the K-means cluster analysis, the sensitivity of the model was tested according to the increased capacity of the field hospitals established in dense areas and the allocation of additional ambulances.

This research aims to optimize the post-disaster humanitarian aid work, which is the most critical stage of transporting the injured to health institutions. The mathematical model's information flow, the suggested patient selection procedure, the data gathered from the field, and this direction have all worked together just to build an integrated framework with the transportation network. The framework optimizes the logistics network by treating the data arriving from the field as demand and the opportunities and capacities that are now available as supply.

2. Literature Review

Activities related to disaster logistics are among the elements of disaster management. According to the generally accepted international definition, disaster management is a general concept that requires the optimum use and management of all opportunities and resources of the society in order to prevent disasters, reduce their damages, provide rapid delivery of search and rescue, first aid and humanitarian aid in the event of a disaster, and then to heal the wounds and return to normal (Ergünay, 2005).

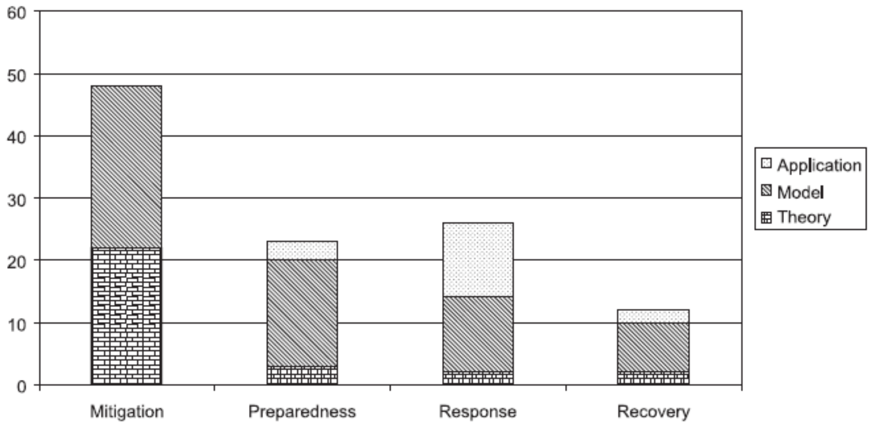

Chart 1: Distribution of Studies by Disaster Management Stages (Altay ve Green, 2006)

There are different types of classifications of disaster management systems in the literature. While Gümüşbuğa (2012) defined the works covering pre-disaster preparedness processes under the risk management activities category, he defined the activities to be carried out during and after the disaster as the crisis management class (Gümüşbuğa, 2012).

Table 1: Disaster Logistics Literature Review Summary

Research Problem	Location, Transportation,	Network Design	Literature Review
Humanitarian Relief Distribution	Knott R. (1987)		
	Haghani and Oh (1996)		
	Barbarosoğlu and Arda (2004)		
	Özdamar et al.(2004)		
	Sheu (2007a)		
	Sheu (2010)	Barbarosoğlu et al. (2002)	
	Tzeng et al. (2007)	Yi and Özdamar (2004)	
	Balcik et al. (2008a)	Yi and Kumar (2007)	
	Wang, S. Ma, Z. And Li, Z. (2008)	Yi, W. and L. Ozdamar (2007)	Altay, N. And Green (2006)
	Vitoriano et al. (2009)	Balcik et al. (2008)	Caunhye et al. (2012)
	Chern vd. (2010)	Özdamar (2011)	Safeer et al. (2014)
	Adivar and Mert (2010)	Sarma et al. (2018)	Arenas et al. (2014)
	Gu (2011)	Konstantinidiou et al. (2019)	
	Hu (2011)	Adrang et al. (2020)	
	Vitoriano et al. (2011)		
Casualty Transport	Yi. W. and Ozdamar, L. (2007)		
	Jotshi et al. (2009)		
	Safeer et al. (2018)		
	Zhu et al. (2019)		

Altay and Green (2006) classified disaster management into four basic stages Mitigation, Preparedness, Response, and Recovery (Altay & Green, 2006).

The classification of operations research in the literature according to disaster management stages is shown in Chart 1. Studies on the intervention phase have been the second most studied area, and it is clear that most of the studies on this area are practice-oriented.

When considering the study subject from the perspective of the disaster logistics literature, it is reasonable to divide the studies into two categories: the distribution of humanitarian aid and the transportation of casualties. In addition to the research examining the two topics concurrently, literature reviews were also noted to exist.

Within the scope of disaster logistics, Knott (1987) made the first study in the field of humanitarian aid logistics (Knott, 1987). Before 2002, when Barbarosoğlu et al. (2002) first looked at the issue of transporting the injured, disaster logistics studies primarily focused on the logistics of humanitarian aid (Adıvar & Mert, 2010; Balcik et al., 2008; Barbarosoğlu & Arda, 2004; Chern et al., 2010; Gu, 2011; Haghani & Oh, 1996; Hu, 2011; Huang et al., 2009; Knott, 1987; Özdamar et al., 2004; Sheu, 2007, 2010; Tzeng et al., 2007; B. Vitoriano et al., 2009; Begoña Vitoriano et al., 2011; Wang, S. Ma, Z. and Li, 2008; Zuo et al., 2014).

The study of Barbarosoğlu et al. (2002) has an important place in the literature as it is the first research that develops a mathematical solution proposal to the problem of transporting injured people (Barbarosolu et al., 2002). In the future, it is observed that there is an increase in the number of studies conducted to solve the transportation logistics problem of injured people (Jotshi et al., 2009; Safeer et al., 2014; Yi & Özdamar, 2007; Zhu et al., 2019).

With the increasing interest in disaster logistics, there are also studies in the literature that deal with both the transportation of humanitarian aid materials and the transportation of the injured at the same time (Adrang et al., 2020; Balcik et al., 2008; Barbarosolu et al., 2002; Konstantinidou et al., 2019; Ozdamar, 2011; Sarma et al., 2018; Yi & Kumar, 2007; Yi & Özdamar, 2004, 2007). There are also literature studies examining disaster logistics problems from different perspectives (Altay & Green, 2006; Anaya-Arenas et al., 2014; Caunhye et al., 2012; Safeer et al., 2014).

In this study, the post-earthquake injured transport problem which is one of the most difficult and critical stages of the disaster management process is discussed. The problem of transporting injured people has been approached from the perspective of logistics network design optimization. This research will hopefully contribute to the field of injured transport, where there is less work compared to humanitarian logistics.

3. Problem Description and Methodology

3.1. Objectives of the study

In a country like Turkey, which has experienced many devastating earthquakes in the past, a large number of injured people will need emergency medical assistance after a potentially severe earthquake. The healthcare system will have a challenging procedure to manage given the urgency of the situation and the scale of the demand for medical support. The aim of this research is to minimize the time between the transportation of seriously injured people to the hospital by ambulances after the earthquake. In line with this goal, a mathematical model was developed, and a new patient selection strategy was proposed.

The proposed mathematical solution model is aimed to optimize the transportation times of the seriously injured from earthquake zones to the hospitals, minimize the waiting times of the patients with the prioritized patient selection strategy and coordinate the transportation process.

It is possible to list the features of the study which differ from the studies in the literature as follows:

- It is a study in which the proposed optimization model and the new patient selection method are integrated. As such, it is one of the few studies in the literature.
- The optimization model has a dynamic structure in which the inputs and constraints change in each period.
- In the literature, there are studies in which the injured were collected and transported at certain points. In this study, transportation was provided to as many different points as the number of injured.
- Ambulance movements are not restricted to a single time in a period as in many studies.
- The model proposed in this study has been tested using real location data.

3.2. Problem Definition

One of the most difficult problems encountered after the earthquake is the problem of transporting many injured people to hospitals. Multidimensional solutions should be developed because there are numerous factors affecting this problem. Within the scope of the proposed solution in this study, an optimization model has been established to minimize the total transportation time by considering parameters such as the capacities of hospitals, their locations, the number of ambulances, and the number of injured.

The research questions are as follows:

- In a region where many people were injured after the earthquake, can the process of transporting the injured to health institutions be improved?
- Can the transportation time of the injured be reduced?
- Can the total migration time be optimized?

Within the scope of the problem, the injured positions were randomly determined in the Tuzla District of Istanbul Province. In the process of transporting injured people to health institutions located within the boundaries of the district, a solution has been developed for the problem of which hospital the patients should be transported to.

3.3. Methodology

A two-stage solution model is proposed to solve this dynamic problem. The mathematical model proposed in the first stage is the mixed integer programming model. The simulation of the mathematical model's outputs using the patient selection method takes place in the second stage. The following are the methods, techniques, and analyses employed throughout the study: K-means clustering analysis was used to show the distribution of the casualties across the county.

- Dijkstra's Shortest Path Algorithm determined the shortest distances between hospitals and the injured.
- Mixed Integer Linear Programming was used to solve the problem of assigning ambulances to patients.
- Branch and Cut Algorithm - CBC was used to solve the Mixed Integer Linear Programming model.
- The patient selection method was used to determine which patients would be visited first.
- With the simulation, "Transferred" and "Remaining" patients were determined at the end of the period.

3.3.1. Problem Assumptions

- Istanbul Province, Tuzla District was chosen as the application area.
- Locations of the injured were randomly selected within the boundaries of Tuzla District.
- Tuzla District of Istanbul Province was evaluated as independent, and patients, ambulances, and hospitals in other neighboring districts were not taken into account.
- The location of the ambulances is the initial station.
- In Istanbul, the total number of ambulances operated by private hospitals is listed, and a hospital-based distribution is made according to bed capacity.
- The 72 hours after the earthquake, which is of critical importance (in which people are most likely to survive with injuries) is defined as 72 periods.
- It is assumed that the total number of seriously injured comes to the system in a different number every hour with an exponential distribution.
- The injured survivors of the earthquake are generally considered to be divided into three classes, which are Lightly Injured, Moderately Injured, and Severely Injured.
- In this study, it was assumed that only seriously injured patients were transported.

- There was no restriction on the number of ambulances during the period.
- The occupancy rates of the hospitals, which vary according to the periods, were taken into account in the referral of the injured to the hospitals.
- Hospitals with full bed capacity are considered to be outpatients.
- Ambulances used the shortest routes during the transportation process.
- The ambulance-hospital pairing was made, and the ambulance which could not bring the patient to the hospital to which it was assigned due to capacity problems were diverted to other hospitals in the other period.
- In Scenario 2 and Scenario 3, it is assumed that patients in hospitals in Tuzla District are evacuated to surrounding provinces.
- In Scenario 2 and Scenario 3, it is anticipated that one field hospital and two field hospitals, respectively, are created in regions with a high patient density.
- Two ambulances are probably allocated to field hospitals.

3.3.2. Mathematical Model

A Mixed Integer Linear Programming model is proposed for the solution of the injured transport problem, and Branch and Cut Algorithm - CBC is used to solve the model. The Sets and Parameters needed to solve the post-disaster casualty logistics problems are as follows:

Sets and Parameters:

- H: Set of hospitals — $h=1,2,\ldots\ldots, H$
- $Hloc$: Locations of hospitals — $Hloc \in H$
- $Hcap$: Capcasities of hospitals — $Hcap \in H$
- P : Set of seriously injured patients — $p=1,2\ldots\ldots P$
- $Ploc$: Locations of patients — $Ploc \in P$
- A : Set of ambulances — $a=1,2\ldots\ldots A$
- a : Location of ambulances — $a \in H$
- t : Time, period — $t=1,2,\ldots\ldots,T$
- ct : Cost of waiting — $ct=1,2\ldots\ldots C$

Decision Variable:

- M : The status of the ambulance being assigned to the relevant patient

Objective Function:

Min. $z = \sum_{t=1}^{T} \sum_{a \in H} \sum_{p \in H} \sum_{h \in H} c_t(T_{a2p} + T_{a2h}).M$

State Variables and Constraints:

$\sum_{h=1}^{H} M = A_{nnp} \; \forall A \in P$ için
$M \in \{0,1\}$

$M \in \{0,1\}$

$M \geq 0$ Patient assignment status

- *Acap* = 1: Carrying capacities of ambulances= 1
- *Anum* ≥ 1: In t period, number of ambulances transporting ≥1
- *Annp*≥ 0: Number of patients that ambulances have to carry per period ≥ 0

  Anap: Number of patients assigned to ambulances to transport in the period
- *Ansp* ≥ 0: Number of patients carried by ambulances per period ≥0
- *Annp* ≥ *Ansp* :Number of patients have to be transported ≥ Number of patients transported
- *Antp* ≥ 0: Total number of patients carried by each ambulance ≥ 0
- *Hcap*: Empty capacities of hospitals at the beginning of period t
- *Htcap*: Total vacant capacity of hospitals at the beginning of period t
- *Hnsp* ≥ 0: Number of inpatients treated by each hospital ≥ 0
- *Hnst* ≥ 0: Number of outpatients per hospital ≥ 0
- *Ptn* ≥ 0: Number of new patients arriving at the start of the t period ≥0
- *Pus* ≥ 0: In the t-1 period, number of patients who could not be reached ≥ 0
- *Ptt* ≥ 0: At the beginning of period t, the total number of patients waiting for an ambulance ≥ 0
- *Ptns* ≥ 0: At the end of period t, number of casualties taken to service ≥ 0
- *Ptnu*: Number of casualties who could not be serviced at the end of period t
- $T_{a2p} > 0$: Ambulance time to reach patient > 0
- $T_{a2h} > 0$: Ambulance return time to hospital > 0
- t ≥ 1: The number of periods ≥1
- $c_t \geq 1$: Cost of waiting for ≥ 1

3.3.3. Patient Selection Method

A separate process is required to determine which of the patients assigned to an ambulance can go first with the solution of the optimization problem. For this purpose, using the penalty coefficient added to the optimization model and determining the patient selection method, the priority of the patients who were assigned an ambulance was determined.

According to the selection procedure to be used, patients who have been assigned should be transported starting with the patient who has the least ambulance coefficient and the shortest journey time. After this selection is made, ambulances will start to transport the patients in the first row and will continue to transport them throughout the period.

A method that prioritizes the periods of stay of the patients and eliminates the long waiting times has been chosen, instead of directing ambulances directly to the shortest appointments. At the end of the simulation, "Transferred" and "Remaining" patients were obtained as output. The remaining patients were included in the optimization problem again in the next period.

3.3.4. Pseudo Code

1. Defining Variables
    At the start of the period, the total number of patients waiting for an ambulance = was 0
    At the beginning of period t, new patients formed
    Patients who could not be reached at time t-1 and remained in the relevant period = 0
2. **for** (period=1; period <= 72 hours; period ++)
    Create a New Incoming Patients list
3. Receive calls
4. Classification of the calls // (Seriously Injured, Moderately Injured, Minor Injured)
5. If seriously injured, start processing
    Add the seriously injured to the New Arrivals list
    Increase the number of new patients formed at the start of the t period
6. Defining Variables
    Total number of patients waiting for an ambulance at the start of period t = new patients formed at the beginning of the t period + Patients who could not be reached in time (t-1) and remained in the relevant period
7. Run the optimization solution
    Ambulance – Create a patient assignment table
    Create patient transport times table
8. Call the simulation algorithm
    End for

Begin the Simulation Algorithm

9. Defining Variables
    A Total Transport Times of Ambulances = 0
    Increase Total Transport Times for each Ambulance by Ambulance transport time
    Number of patients transported for a period = 0

Increase the period transported number by the number of ambulances transporting patients
Number of patients remaining period = 0
Increase the number of the period remaining by the number of patients remaining in the ambulance

10. Sort the list in ascending order by migration time
11. Sort the list ascending by penalty coefficient (period coefficient)
12. for (ambulance=1; ambulance<= 15; ambulance++)

Create a new Ambulance transporter list
Create a new Ambulance remaining list
Number of ambulances transported = 0
Number of ambulances left = 0
Ambulance transport time = 0
for (patient=1; patient<= number of patients assigned to ambulances; patient++)
if Ambulance transport time <=((period*60)+patient transport time)
Add ambulance transported list ($\text{Patient}_{(\text{index})}$)
Increase the number of ambulances transported
Increase the ambulance transport time by the patient transport time
Else
Add Ambulance Remaining list ($\text{Patient}_{(\text{index})}$)
Increase the number of Ambulance Remaining
End if
End for patient
End for ambulance

4. Results

4.1. Data

In the study, the reports published by institutions such as the Ministry of Health, Istanbul Provincial Health Directorate, TurkStat (Turkish Statistical Institute), AFAD (Disaster and Emergency Management Presidency), and data obtained from public databases were used. Many detailed data such as hospitals, ambulances, doctors, and health workers within the borders of the province were obtained from the Provincial Health Directorate.

For the application of the proposed mathematical model and patient selection model, Istanbul Province, where a severe earthquake is expected shortly, and Tuzla District, which is one of the riskiest regions, were selected. According to the earthquake forecast results, in the event of an earthquake with a magnitude of 7.4 in Istanbul, 51108 seriously injured are expected. According to these estimates, it is predicted that 1394 people were rescued with serious injuries during the 72-hour rescue operations in Tuzla.

In addition to these, the OSMnx library in Python was used to determine the locations of possible seriously injured in the Tuzla District and create distance matrices (Boeing, 2017).

Information about the hospitals and ambulances to be used within the scope of Scenario 1, Scenario 2, and Scenario 3 is as in Table 2:

- H, Private Tuzla, Okan University, Tuzla State, Gisbir, Aydınlı Field, Şifa Field
- P, p= 1,2,3….,1394
- A, a= A1, A2 ……,A18, A19
- Hcap = 909
- P _total = 1394
- A_total = 19

Table 2: Distribution of Ambulances by Hospitals in Tuzla District, 1,2, 3

Scenarios			Hospital	Osm_Id	Latitude	Longitude	Numb. Amb.
Scenario 3	Scenario 2	Scenario 1	Tuzla State Hospital	2230026598	40.845280	29.302440	6
			Okan University Hospital	6767716363	40.849384	29.301822	6
			Gisbir Hospital	2365236395	40.847839	29.294578	2
			Private Tuzla Hospital	1974824938	40.826042	29.310320	1
			Aydınlı Field Hospital	2265386405	40.877597	29.337894	2
			Şifa Field Hospital	6131299430	40.835566	29.365106	2
			Total:				**19**

The estimated casualty estimates after the earthquake are exponentially distributed over the 72-hour period when the probability of recovery is highest. The frequency of rescue of the patients shows an exponential distribution. A significant intensity was present during the early hours, but as the hours went on, decreasing numbers of individuals were being rescued, and in some instances, nobody was being saved at all.

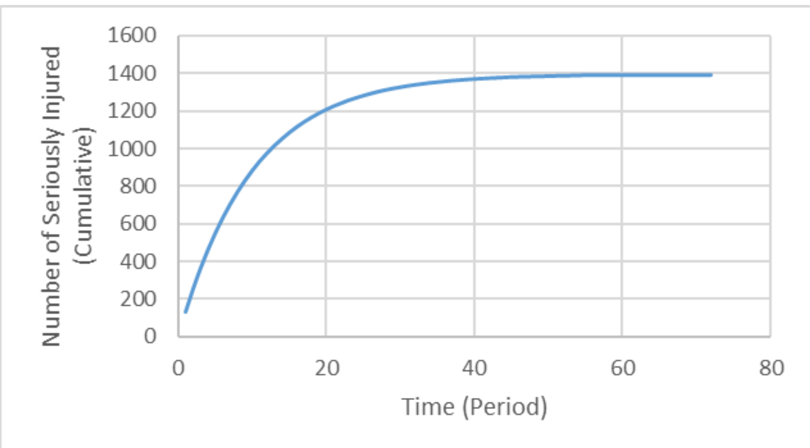

Chart 2: Number of Seriously Injured by Periods

Chart 2 shows the cumulative distribution of patients rescued by period. It is clear in the graph that the distribution of the recovery times of the patients and the arrival of the information to the system is in accordance with the exponential distribution.

4.2. Data Analysis and Results

There are 5475 Nodes and 14527 Edges registered for the Tuzla district in the Osmnx library. The expected serious injured were determined completely randomly among the nodes within the district. According to the results of the K-means clustering analysis, the locations of 1394 seriously injured randomly selected throughout the district are shown in Chart 3.

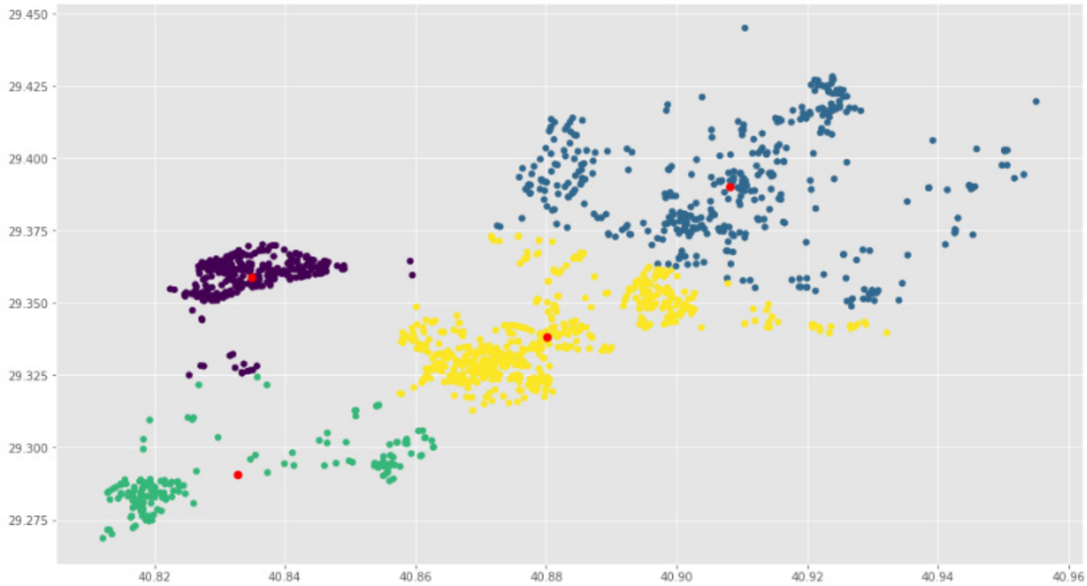

Chart 3: Geographical Distributions and Clusters of Seriously Injured People

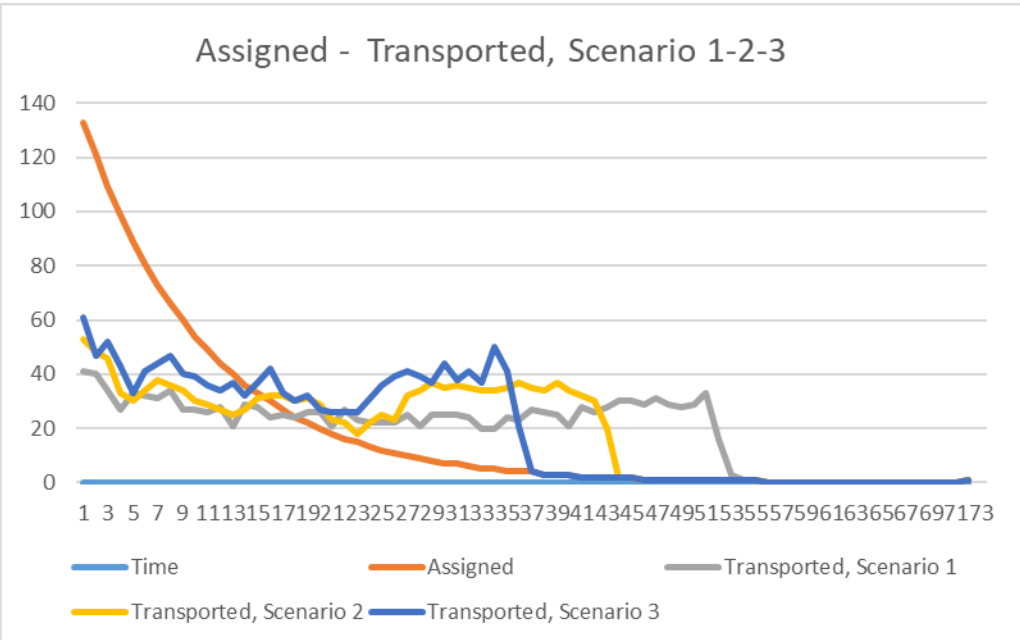

Chart 4: Number of Newly Assigned and Transported Patients, Scenario 1-2-3

How the proposed mathematical model works in the current order and capacity has been tested with scenario 1, and it has been determined that the ambulances and hospital capacities are insufficient. As can be seen in Chart 4, only the process of transporting the seriously injured takes more than two days and 52 hours. The prolongation of the transportation process will result in more fatalities. With 401 beds available, the current (Scenario 1) situation can fully accommodate just a very small portion of the badly injured's treatment requirements. The majority of injured people are handled in temporary treatment centers or outpatient treatment centers, it has been observed.

It is inevitable to take additional measures to increase the capacity of the treatment services supplied to the injured, and thus shorten the service period. For these reasons, cost-effective, realistic, applicable, and sustainable solutions are needed. In this context, Sensitivity Analysis was performed to determine the effects of additional measures on the proposed mathematical model.

With the sensitivity analysis whose results are shared in Table 3, the significant decrease in the objective function is important in terms of showing the effectiveness of the additional capacities produced. It is noteworthy as it reflects the sensitivity of the mathematical model.

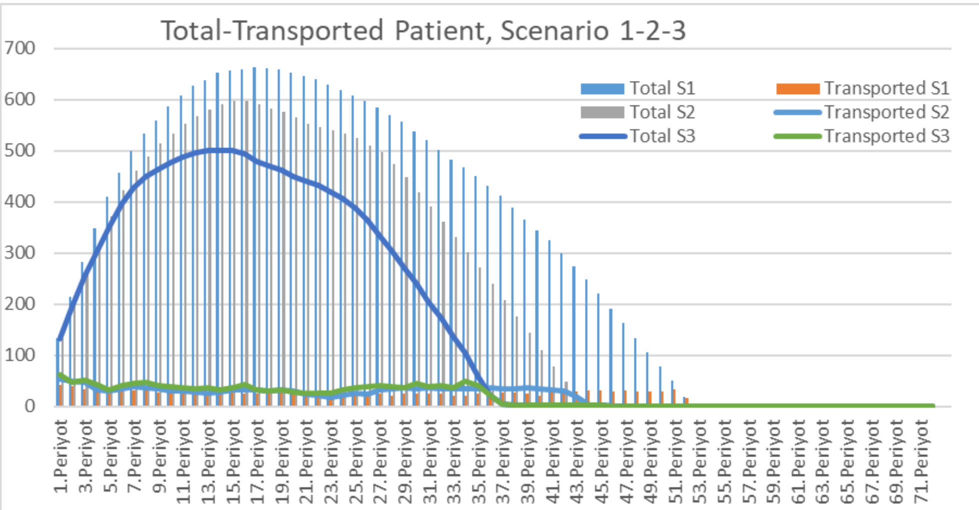

Chart 5: Total Number of Patients and Transported Patients, Scenario 1-2-3

In Scenario 2, it is possible to see the effect of the 2 ambulances allocated together on the waiting times and crowding of the patients with the establishment of Şifa field hospital in Chart 5. Although the capacity increase in Scenario 2 was partially effective, they were not at a level that could eliminate the waiting when the system was busy. The improvements made have resulted in improvements in the system, from a 52-hour transit time to a 43-hour transit time. The 9 hours of healing obtained is not enough time due to the serious condition of the injured.

When a field hospital was established in the Aydınlı region, where the patient density is high and there is no hospital, it was observed that the system accelerated, and accumulations disappeared earlier. With the implementation of scenario 3, the patients waiting at the end of the 36th period were reset, and the system was able to transport the incoming patient. There has been an improvement of 16 hours in the current situation (scenario 1) and an improvement of 7 hours in scenario 2. Therefore, even though Scenario 3 may be

Table 3: Sensitivity Analysis Results

Scenario 1					
Number of patients=	1394	Number of hospitals=	4	Number of Ambulance=	15
				Objective Function=	**462.585,49**
Hospitals	**Bed Capacities**	**Number of Patients Assigned**	**Inpatient**	**Outpatient**	**Total Transported Patients**
Tuzla State Hospital	185	535	185	340	525
Okan University Hospital	137	415	137	405	542
Gisbir Hospital	51	284	51	160	211
Private Tuzla Hospital	28	160	28	88	116
Total =	**401**	**1394**	**401**	**993**	**1394**
Scenario 2					
Number of patients =	1394	Number of hospitals =	5	Number of Ambulance=	17
				Objective Function=	**405.426,42**
Hospitals	**Bed Capacities**	**Number of Patients Assigned**	**Inpatient**	**Outpatient**	**Total Transported Patients**
Tuzla State Hospital	355	612	355	174	529
Okan University Hospital	244	420	244	185	429
Gisbir Hospital	81	140	81	48	129
Private Tuzla Hospital	29	50	29	38	67
Şifa Field Hospital	100	172	100	140	240
Total =	**809**	**1394**	**809**	**585**	**1394**
Scenario 3					
Number of patients =	1394	Number of hospitals =	6	Number of Ambulance=	19
				Objective Function=	**382.382,37**
Hospitals	**Bed Capacities**	**Number of Patients Assigned**	**Inpatient**	**Outpatient**	**Total Transported Patients**
Tuzla State Hospital	355	545	355	136	491
Okan University Hospital	244	374	244	122	366
Gisbir Hospital	81	124	81	37	118
Private Tuzla Hospital	29	45	29	26	55
Aydınlı Field Hospital	100	153	100	60	160
Şifa Field Hospital	100	153	100	104	204
Total =	**909**	**1394**	**909**	**485**	**1394**

considered good in light of the current circumstances, it is obvious that more is needed for seriously injured patients.

4.3. Sensitivity Analysis

In this study, the sensitivity of the model was tested on two main constraints of the model, namely the number of hospitals and the number of ambulances. In two different scenarios alternative to the current situation, new field hospitals and new ambulances have been integrated into the system. As a result of the sensitivity analysis, it is seen in Table 3 how the location of the hospitals to be established for the improvement of the system and the increase in the number of ambulances changed the objective function.

While the changes in the constraints affected the objective function, they also affected the waiting times of the patients and facilitated to end of the congestion in the system earlier. In addition, the effects of the transported wounded on the type of service they receive from the hospitals were observed. Thanks to the increased bed capacity, the number of inpatients has increased, and the number of outpatient/temporary treatment patients has decreased.

When comparing Scenario 2 to the current situation with the increased bed capacity as a result of evacuating the inpatients in the hospitals after the disaster, as well as the establishment of 1 field hospital and the distribution of 2 ambulances, the results of the sensitivity analysis in Table 3 show that objective function has decreased by roughly 12.36 percent from “462585.49” to “405426.42.” With the implementation of scenario 3, the objective function decreased by approximately 17.34% to the level of “382382.37”.

The results show how sensitive the proposed mathematical model is to the changing constraints in Scenario 2 and Scenario 3. It can be said that the changes in the objective function are at significant levels as a percentage.

5. Discussion

5.1. Conclusions

The delivery of necessities to a disaster victim as well as the evacuation of persons affected by the disaster to safe locations is both included in the logistics of post-disaster humanitarian relief. The issue of conveying the badly injured to healthcare facilities during the post-earthquake response period was investigated in this study. The problem has been solved with the proposed mixed integer programming model and patient selection method in order to minimize the time elapsed until the patients who survived the earthquake with severe injuries are transported to health institutions.

According to the results of the clustering analysis, the establishment of field hospitals in the regions where the patients are dense but there is no hospital-enabled distribution of the load accumulated in the system. On the one hand, field hospitals offered additional bed capacity; on the other hand, they reduced the distance that ambulances had to travel. The improvements observed in Scenario 2 and Scenario 3 are very important in terms of showing the sensitivity of the model.

5.2. Limitations and Future Research

The system created to address the issue is only comprised of land ambulances, but it can be improved by integrating air and sea vehicles. The application of the study was carried out in the Tuzla district in scope. In a system that will include neighboring provinces and districts, the objective function can be made more optimal thanks to resource sharing.

In a study to be carried out with the integration of Istanbul and neighboring provinces, it may be possible to optimize the treatment processes of more injured people by preventing idle capacity. In future studies, solutions obtained from different numerical techniques such as heuristic and metaheuristic techniques will contribute to the development of the decision mechanism.

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