Sigma Journal of Engineering and Natural Sciences
Web page info: https://sigma.yildiz.edu.tr
DOI: 10.14744/sigma.2024.00120

Research Article

A sample application for scheduling search and rescue teams in an earthquake disaster

Elif AKDAŞ[1], Tamer EREN[1,*]

[1]*Department of Industrial Engineering, Kırıkkale University, Kırıkkale, 71450, Türkiye*

ARTICLE INFO

Article history
Received: 28 May 2017
Accepted: 08 August 2017

Keywords:
Disaster Management; Earthquake; Staff Scheduling; Search and Rescue Teams; Goal Programming

ABSTRACT

Disasters that occur unexpectedly cause many material and moral losses. Türkiye is an earthquake zone that frequently experiences earthquakes as a result of the convergence of the plates. The period in which earthquakes will occur is unknown, but the damage caused by the necessary planning can be reduced. Disaster management, which is a dynamic and versatile process, is a system that requires effective organization to minimize losses and damages. In the response phase of disaster management, search, and rescue teams work against time pressure by undertaking complex tasks in their live-focused debris work in multiple and scattered disaster areas. In the 6 February 2023 Kahramanmaraş earthquakes, it has been seen how important it is to dispatch the teams to the regions quickly. In this study, the problem of scheduling 380 Disaster and Emergency Management Presidency (AFAD) search and rescue teams to be dispatched to 8 areas where destruction was experienced was handled by considering the earthquake scenario in a province located in a risky region. The purpose of the problem is to dispatch the appropriate number of teams to the correct disaster areas. The mathematical model created with the goal programming method is solved with the IBM ILOG optimization program. According to the solution results obtained, the optimal assignment and schedule of the teams are created by providing the targeted constraints.

Cite this article as: Akdaş E, Eren T. A sample application for scheduling search and rescue teams in an earthquake disaster. Sigma J Eng Nat Sci 2024;42(5):1555−1562.

INTRODUCTION

Disasters that occur suddenly are a situation that requires the coordinated work of many institutions and organizations. Türkiye is located between the African and Arabian plates and the Eurasian plates. Türkiye is an earthquake country that frequently experiences tectonic earthquakes caused by plate movement. According to the Earthquake Zones Map, 92% of the country is in earthquake zones, and 95% of the population lives under earthquake risk [1].

An earthquake is an event that causes loss of life by shaking the surface that we know as immobile and damaging the structures on it [1]. The time of the earthquake's occurrence is unknown, but all the work done to reduce the damage it may cause is the subject of disaster management [2]. Disaster management, which is a dynamic and

***Corresponding author.**
*E-mail address: tamereren@gmail.com, meakdas9@gmail.com

This paper was recommended for publication in revised form by Regional Editor Omid Mahian

multifaceted process, includes organizing and managing the activities needed to reduce the adverse effects of disasters. Search and rescue, first aid, evacuation, prevention of secondary disasters, etc., work is carried out by teams.

Disasters that cause significant damage make managing search and rescue efforts difficult. This reveals the difficulty of sending teams to disaster areas. Emergencies are sudden, uncertain, and devastating. Search and rescue teams often face challenging tasks in multiple and scattered disaster areas. Because disaster and relief situations are complex, emergency decision-makers must reasonably and quickly assign teams to disaster areas. Therefore, determining the optimum distribution of teams is a valuable research topic [3]. This situation requires an effective organization to send swiftly teams to areas requiring search and rescue [4]. Search and rescue efforts, which started immediately after the buildings collapsed and the people were trapped in the buildings, started and continued sequentially and continuously. As soon as the disaster occurs, search and rescue efforts begin with the people in the immediate vicinity rushing to help with their means. With effective communication and transportation means, these studies continue with regional or national support after local disaster and emergency services reach the region [5].

It has been seen that the 6 February 2023 Kahramanmaraş earthquakes that occurred recently on the Eastern Anatolian Fault (EAF) caused significant material and moral losses and it is essential to direct the teams quickly. According to scientific predictions, the stress emitted by fault lines broken in earthquakes in this region may have been transferred to other nearby fault lines. EAF has the potential to produce large earthquakes. The province of Elazığ, located on this fault, is in the first-degree earthquake zone and is within the impact area of many active faults. One of the earthquakes that will significantly affect Elazığ Province is the earthquakes that may occur in the Palu segment between Gökdere and Hazar Lake. EAF line is very close to the Palu and Kovancılar districts of Elazığ Province. The geological structure of the center of Palu increases the destructiveness in case of an earthquake. These reasons increase the effect of the earthquake. In addition, alluvial ground in the plains of the center of Elazığ will cause more building damage in possible earthquakes [6]. To reduce post-earthquake chaos and information pollution, earthquake scenarios are produced by the AFAD Earthquake Department. Scenarios are analyzed with the AFAD-RED analysis program. The outputs of the program produce estimation results for potential losses. With these results, it is aimed to send the teams to the right disaster areas as soon as possible.

In this study, the province of Elazığ, a first-degree earthquake zone, is handled. In the scenario used, it is known that 8 districts will be destroyed in an earthquake with a magnitude of 7.3 in Elazığ. The problem of scheduling the AFAD search and rescue teams to be dispatched to the disaster areas where the destruction occurred is discussed to keep the losses to a minimum. The problem of dispatching teams to districts with collapsed buildings is NP-hard; therefore, goal programming is used. A mathematical model is created with the goal programming method to send the teams to the districts where the collapsed buildings are located. This problem aims to dispatch the appropriate number of teams to the right disaster areas.

LITERATURE REVIEW

This study discusses the scheduling of search and rescue teams in disaster management, and the literature review on the subject is presented in this section.

[7] aimed to address the assignment problem during the search and rescue period to reduce the earthquake's death toll and allocate resources to earthquake zones. He created an optimized resource schedule using simulated annealing and tabu search heuristics. [8] aimed at the logistics system that assists disaster victims, which is formulated as a multi-objective optimization problem, and one of the objective functions is to minimize the total travel time. [9] aimed at a decision support system that aims to plan rescue units and assign units to incidents. They proposed a nonlinear optimization model and proposed a Monte Carlo-based heuristic solution. [10] aimed to allocate and schedule recovery units with a biased random key genetic algorithm to minimize the sum of the fuzzy processing times of the events and the weighted completion time according to the severity level. [11] aimed to allocate emergency units to the scene, and casualties at the scene to get the injured out of the red and yellow triage in the first hours of the disaster. [12] aimed to a model for the assignment of rescue units to multiple disaster areas, taking into account the compatibility between the skills and duties of the rescuers. [13] aimed to allocate and schedule to minimize completion time in response to rescue teams. They used the complex integer programming model and the GRASP metaheuristic method. [14] aimed at the problem of allocation and scheduling of rescue units with the learning effect. The problem is likened to the disconnected parallel machine scheduling and traveling salesman problem. They benefited from multi-objective goal programming and robust optimization methods. [15] aimed at the task assignments of rescue teams in local search and rescue operations. They created three scenarios with different earthquake magnitudes and uncertainty. [16] aimed at the problem of scheduling the teams conducting urban search and rescue operations in an earthquake disaster. They used mathematical programming to decide which team would be dispatched to which scene. [17] aimed to determine the search and rescue teams coming to Türkiye for international assistance in disaster management planning. Multi-criteria decision-making techniques AHP and TOPSIS methods were used to determine the teams. [4] aimed at dispatching rescuers to multiple disaster areas and different rescue points. They used the evidence-based best-worst method and Dempster-Shafer theory-based modeling to

maximize rescue time satisfaction and rescuer competence for dispatching rescuers to multiple disaster sites. [18] with queuing theory, aimed to determine the number of rescuers in search and rescue operations. The damages to the buildings, the number of injured, the determination of the service period, the simulation model design, and the victims' survival rates were calculated and compared with the duration of the rescue operations. [19] aimed at the problem of assigning rescue units with the data from the flood disaster in Iran. Fuzzy robust optimization and hybrid metaheuristic algorithms minimize the sum of weighted completion times of recovery operations. [20] aimed at the assignment problem of rescuers, taking into account the skill levels, preferences, joint knowledge, and rescue operation time of the rescuers. [21] aim at the scheduling problem of search and rescue and psychosocial support teams in areas with collapsed buildings in the Erzincan earthquake. They used goal programming method as solution method. [22] aim at the scheduling problem of search and rescue teams in the disaster districts where the destruction occurred in the Aydın earthquake, the epicenter of which was the town of Efeler, using the target programming method.

In addition, applications were made in different fields by using various methods of personnel scheduling, which is the subject of this study. It is desired to give brief information about the application areas of these studies. In the energy sector [23], in the retail sector [24], in the manufacturing sector [25, 26], in the shift scheduling [27, 28], in the nurse scheduling [29, 30], in the service sector [31, 32], in the security staff scheduling [33] applications were made in the textile sector [34]. In addition, [35] conducted a literature review study with the goal of programming methods in service systems and [36] with personnel scheduling problems.

The goal programming method used in this study has also been used to solve many other problems. If we talk about some studies to give information, an integrated approach to supplier selection with goal programming and [37, 38], for project selection [39, 40], surgical operation scheduling with goal programming and constraint programming [41], in sustainable personnel scheduling [42], in the operating room scheduling with surgical team problem [43] handled their studies with the goal programming method. The summary of the research articles cited in the literature review section is given in Table 1.

GOAL PROGRAMMING

The goal programming method, a multi-criteria decision-making technique, is different from the frequently used and single-purpose linear programming; in this method, the objective function targets more than one purpose. The product of the objective function's positive and negative deviation variables should be equal to zero. In other words, while one of the deviation variables gets a value greater than zero, the other deviation variable is equal to zero, and they cannot take a negative value. In the objective function, these deviation values are tried to be minimized. The formulation of the goal programming method is shown in Equations 1-3 [44].

x_j: j.decision variable
w_{ij}: i.target j.decision variable coefficient
k_i: the desired value for the target i.
d_i^+: positive deviation value of i.target
d_i^-: negative deviation value of i.target

$$Min\ Z = \sum_{i=1}^{n} (d_i^+ + d_i^-) \tag{1}$$

$$\sum_{j=1}^{m} w_{ij} * x_j - d_i^+ + d_i^- = k_i \tag{2}$$

$$x_j, d_i^+, d_i^- \geq 0 \qquad \forall_{i,j} \tag{3}$$

Equation 1 expresses the objective function of the model. Equation 2 is the target constraint k_i is the right-hand side value that is trying to be reached. If Equation 3 is the hard constraint in the model, the model is unsolvable.

APPLICATION

In the application, the province of Elazığ, located in the 1st-degree earthquake zone and frequently exposed to earthquakes, is handled. It is desired to keep the losses to a minimum due to a possible Elazığ earthquake. Therefore, the study used the outputs of an earthquake scenario created by AFAD. The flowchart of the problem is given in Figure 1.

Problem Identification

The problem of scheduling the search and rescue teams that will be dispatched to the districts where the destruction occurred when an earthquake with a magnitude of 7.3 occurred as a result of the complete rupture of the Palu segment on the EAF and also in the southeast of Elazığ Province, is discussed. In this study, "Which AFAD search and rescue teams should be sent to which district?" search for an answer to the question. The problem in question is an NP-hard problem, and the goal programming method is used in its solution.

Data Collection

To solve the problem of scheduling the search and rescue teams, information is collected about the districts affected by a possible earthquake and search and rescue teams in the Palu segment. The information obtained is listed below.

- An earthquake scenario that will occur in the Palu segment
- Seismic intensity distribution map (Annex-1)
- Building damage graph

Figure 1. Flowchart.

Identification of Disaster Areas

The devastating effect of the earthquake, which is felt at different intensities in approximately 13 provinces, is seen in Elazığ Province. It has caused damage to buildings in 8 districts, including Alacakaya, Arıcak, Karakoçan, Kovancılar, Maden, Merkez, Palu, and Sivrice. According to the number of building damage, Elazığ Center and Kovancılar districts are affected the most. It is felt in the provinces of Adıyaman, Batman, Bayburt, Bingöl, Diyarbakır, Elazığ, Erzincan, Erzurum, Malatya, Mardin, Muş, Siirt and Tunceli. While the earthquake is felt very intensely in some provinces, it is felt less intensely in others. In this study, search and rescue activities will be carried out in 8 districts, namely Alacakaya, Arıcak, Karakoçan, Kovancılar, Maden, Merkez, Palu, and Sivrice, where buildings are ruined.

Determination of Search and Rescue Teams

Search and rescue teams undertake a difficult task, aiming to save disaster victims and minimize losses by conducting search and rescue operations on collapsed building debris or in any area. As a result of the demolitions in Elazığ districts, the number of search and rescue teams dispatched to the districts is determined by a ratio of approximately 1/10 to the number of collapsed buildings. 8 AFAD teams can be dispatched from the provinces where the Union Directorates are located, and 1 or 2 AFAD teams from the provinces where the Provincial Directorates are located. The number of teams determined according to the demolition in the districts is given in Table 2.

Table 1. Number of Buildings and Teams by Districts

District	Number of ruined building	Number of teams
Alacakaya	31	4
Arıcak	9	1
Karakoçan	167	17
Kovancılar	1499	150
Maden	275	28
Merkez	293	30
Palu	1472	148
Sivrice	5	1

Districts with collapsed buildings, the number of collapsed buildings, and the number of teams to be dispatched to districts are seen in Table 1.

Establishment of The Mathematical Model

"Which AFAD search and rescue team should be assigned to which district?" A model is created using the goal programming method to decide the question in a short time and in a reasonable way.

Parameters:

n = number of teams

m = number of zones

i = team index $i = 1,2, \dots, N$

j = county index $j = 1,2, \dots, M$

Decision variables:

$$x_{ij} = \begin{cases} 1, If\ the\ i.team\ is\ assigned\ to\ the\ j.district \\ 0, other\ situations \end{cases} \quad \forall_{i,j}$$

d_{ik}^{+} = positive deviation value of the i. team from the kst target (i=1,2,…, 380; k=1,2,…, 11)

d_{ik}^{-} =negative deviation value of the i. team from the kst target (i=1,2,…, 380; k=1,2,…, 11)

Constraints:

$$\sum_{i=1}^{n} x_{ij} \geq 1 \quad \forall_j \tag{1}$$

$$\sum_{j=1}^{m} x_{ij} \leq 1 \quad \forall_i \tag{2}$$

$$\sum_{i=1}^{n} x_{ij} - d_{i1}^{+} + d_{i1}^{-} = 4 \quad j = 1 \tag{3}$$

$$\sum_{i=1}^{n} x_{ij} - d_{i2}^{+} + d_{i2}^{-} = 1 \quad j = 2,8 \tag{4}$$

$$\sum_{i=1}^{n} x_{ij} - d_{i3}^{+} + d_{i3}^{-} = 17 \quad j = 3 \tag{5}$$

$$\sum_{i=1}^{n} x_{ij} - d_{i4}^{+} + d_{i4}^{-} = 150 \quad j = 4 \tag{6}$$

$$\sum_{i=1}^{n} x_{ij} - d_{i5}^{+} + d_{i5}^{-} = 28 \quad j = 5 \tag{7}$$

$$\sum_{i=1}^{n} x_{ij} - d_{i6}^{+} + d_{i6}^{-} = 30 \quad j = 6 \tag{8}$$

$$\sum_{i=1}^{n} x_{ij} - d_{i7}^{+} + d_{i7}^{-} = 148 \quad j = 7 \tag{9}$$

$$\sum_{i=1}^{112} x_{ij} - d_{i8}^{+} + d_{i8}^{-} = 40 \quad j = 4 \tag{10}$$

$$\sum_{i=1}^{112} x_{ij} - d_{i9}^{+} + d_{i9}^{-} = 16 \quad j = 5 \tag{11}$$

$$\sum_{i=1}^{112} x_{ij} - d_{i10}^{+} + d_{i10}^{-} = 16 \quad j = 6 \tag{12}$$

$$\sum_{i=1}^{112} x_{ij} - d_{i11}^{+} + d_{i11}^{-} = 40 \quad j = 7 \tag{13}$$

$$\min Z = \sum_{i=1}^{n} (d_{ik}^{+} + d_{ik}^{-}) \quad \forall_k \tag{14}$$

$$x_{ij} = 0\ or\ 1 \quad \forall_{i,j} \tag{15}$$

$$d_{ik}^{+} + d_{ik}^{-} \geq 0 \quad \forall i_{,k} \tag{16}$$

Constraint (1) ensures that at least one team is assigned to each county, and Constraint (2) ensures that each team is assigned to at most one county. Constraints (3)-(13) range are the goal constraints of the problem. The constraints in the range (10)-(13) are for the teams dispatched from the province where the Union Directorate is located to the disaster districts where destruction is high. The Constraint (10) ensures that 40 teams from 5 provinces where the Union Directorate is located go to the Kovancılar district of Elazığ. Constraint (11) ensures that 16 teams from 2 provinces where the Union Directorate is located go to the Maden district of Elazığ. Constraint (12) ensures that 16 teams from 2 provinces where the Union Directorate is located go to the Merkez district of Elazığ, and Constraint (13) ensures that 40 teams from 5 provinces where the Union Directorate is located go to the Palu district of Elazığ. Constraint (14) is the objective function of the problem, and Constraint (15)-(16) is the sign constraint.

EVALUATION OF SOLUTION RESULTS

According to the solution results obtained, are dispatched 4 teams to Elazığ Alacakaya district, 1 team to Elazığ Arıcak district, 17 teams to Elazığ Karakoçan district, 150 teams to the Elazığ Kovancılar district, 28 teams to Elazığ Maden district, 30 teams to Elazığ Elazığ Merkez district, 148 teams to Elazığ Palu district and 1 team to Elazığ Palu district. The target constraints between constraints (3) and (13) are provided. 40 of the 150 teams sent to Kovancılar district are sent from the Union Directorate. 16 of the 28 teams sent to Maden district are sent from the Union Directorate. 16 of the 30 teams sent to Merkez district are sent from the Union Directorate. 40 of the 148 teams sent to Maden district are sent from the Union Directorate. The solution results are shown in Figure 2.

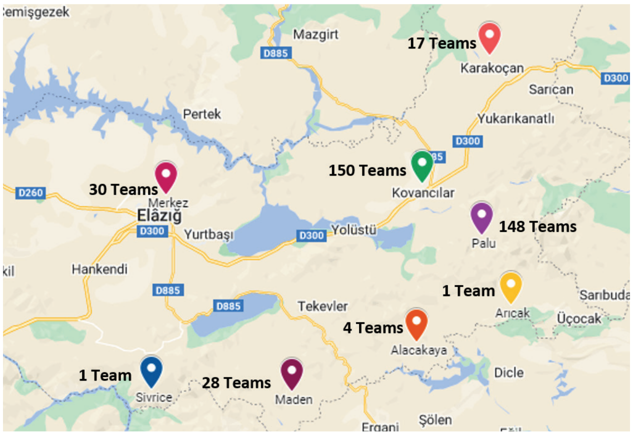

Figure 2. Solution Results.

CONCLUSION

An effective management system is needed to reduce the negative effects of the disaster. Disaster management, a versatile and dynamic system, consists of four stages: damage and risk reduction, preparedness, response, and recovery. Different studies are carried out in each of these stages. In this study, search and rescue teams, which are actively involved in the intervention phase, are discussed. When the studies in the literature are examined, this study will likely guide the search and rescue teams in disaster management in personnel scheduling.

In this study, a 7.3 magnitude earthquake scenario that will occur in the Palu segment of Elazığ Province is handled. 8 disaster areas are estimated to be affected by the earthquake. The problem of scheduling AFAD search and rescue teams to these regions has been addressed. The problem is NP-hard; therefore, the goal programming method is used. The application is continued by using the statistical outputs of this scenario, which is created with an analysis program by the AFAD Earthquake Department. According to the solution results obtained, are dispatched 4 teams to Elazığ Alacakaya district, 1 team to Elazığ Arıcak district, 17 teams to Elazığ Karakoçan district, 150 teams to the Elazığ Kovancılar district, 28 teams to Elazığ Maden district, 30 teams to Elazığ Elazığ Merkez district, 148 teams to Elazığ Palu district and 1 team to Elazığ Palu district.

This study assumes that search and rescue operations are carried out in the ruined buildings. However, suppose there is a disaster victim (disabled, elderly, paralyzed, etc.) who cannot go out by his means in heavily damaged buildings. In that case, rescue works can be carried out. 2 out of 16 provinces with a union directorate are excluded because search and rescue teams in the disaster-affected region cannot be included because they are responsible for their regions. While planning, the maximum number is calculated while determining the number of teams to be dispatched to the areas due to the uncertain and destructive nature of the disaster.

The occurrence of earthquakes that caused significant losses in the past is a herald of earthquakes of similar magnitudes in the future. To be a disaster-resilient society, it is necessary to prepare for disasters by making essential pre-disaster planning. In future studies;

- Unlike this study, which is carried out considering the ruined buildings, older people, paralyzed, disabled, etc., In the case of disaster victims, the study can be expanded by adding new constraint(s) to the model.
- If the number of teams is insufficient, more teams can be assigned to disaster areas where destruction is high using the weighted and priority goal programming method.
- Since the mathematical models created can be used for various scenarios in different earthquake regions, similar studies can be conducted, especially considering the regions where scientists expect earthquakes shortly.
- Appointments and schedules can be created for other teams involved in disaster management, such as firefighters and health teams, who undertake different tasks. While creating these charts, they can be combined with the shortest path problems by considering the positions of the teams to be assigned according to the disaster areas and the team assignment.

NOMENCLATURE

AFAD Disaster and Emergency Management Presidency
EAF Eastern Anatolian Fault

ACKNOWLEDGEMENT

I want to thank Adana AFAD search and rescue technician Hikmet Eroğlu, who shared the necessary information during the implementation phase of the Research. Kırıkkale University's BAP Coordination Unit supports this study.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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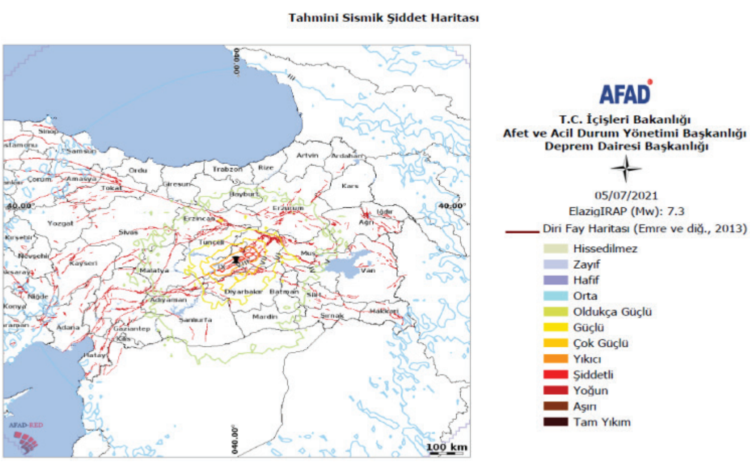
ANNEX

Annex-1



(Reference: https://Elazığ.afad.gov.tr/il-planlari)