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Assignment of Search and Rescue Teams to Adalar District: Possible Marmara Earthquake

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Abstract

Disaster management includes efforts to reduce the negative effects of a disaster. This management system has various challenges. Teams need to be sent to disaster areas as soon as possible to reduce losses and damages. Turkey, which frequently experiences earthquake disasters, has recently experienced the 2023 Kahramanmaraş earthquakes. After the recent earthquakes, the Great Marmara Earthquake, which scientists emphasize the most, has started to be discussed. It is said that Istanbul will be affected very much. Possible earthquake scenarios with a magnitude of 7.5 have been produced. In this study, Adalar district, which will be affected by the Great Marmara Earthquake, is considered and the problem of assigning teams to very heavily damaged buildings is discussed. For the continuation of the study, the data in the Istanbul Province Adalar District Possible Earthquake Loss Estimates Booklet is used. The 413 severely damaged buildings in the 5 neighborhoods where the destruction will occur and the number of building floors in the neighborhoods are taken into consideration. A mathematical model was created for the problem with the goal programming method. The model was solved with the Cplex solver of IBM ILOG optimization program. Thus, the optimal team assignment was realized.

Keywords: disaster management, search and rescue, marmara earthquake, istanbul, optimization, goal programming

1. Introduction

Turkey is an earthquake country that frequently experiences tectonic earthquakes caused by the movement of plates. According to the Earthquake Zones Map, 92% of Turkey is an earthquake zone and 95% of its population lives at risk of earthquakes. An earthquake is an event that causes loss of life by shaking the surface we know as motionless and damaging the structures on it.

It is unknown when the earthquake will occur, but all efforts to reduce the damages are the subject of disaster management. When an earthquake occurs, search and rescue, first aid, evacuation, prevention of secondary disasters, etc., are carried out by the necessary search and rescue teams. The earthquake, which causes significant damage, makes it difficult to carry out search and rescue activities in a coordinated manner. This reveals the difficulty of sending teams to disaster areas. It requires effective organization for emergency decision-makers to dispatch teams to disaster areas in a reasonable but rapid manner [1]. The complexity of disasters and emergencies affects the rapidity of this decision. Search and rescue operations that start immediately after the collapse of structures and trapping of people inside these structures continue sequentially and continuously. As soon as the disaster strikes, people in the immediate vicinity rush to help with their means. Search and rescue teams reaching the disaster areas face challenging tasks in multiple and dispersed disaster areas.

As a result of risk assessment studies, earthquake scenarios are created to estimate losses and damages in case of hazards at various locations and regions. These scenarios differ according to the time of the earthquake as day and night earthquake scenarios. In nighttime earthquakes, most people are considered to be in their homes. Accordingly, loss of life may be caused by damage to residential buildings.

In this study, we consider the problem of assigning search and rescue teams to the Adalar district of Istanbul in the event of a 7.5-magnitude Marmara Earthquake. According to this deterministic earthquake scenario, the earthquake will occur at night and search and rescue teams will be dispatched to heavily damaged buildings in 5 neighborhoods in the district.

2. The Seismicity of Istanbul Province

The tectonic structures controlling the earthquake hazard of Istanbul are expected to be the northern branch segments of the North Anatolian Fault, also called the Main Marmara Fault, located within the Marmara Sea. The western part of the North Anatolian Fault in the Sea of Marmara was ruptured in the 1912 earthquake, and the eastern part was ruptured in the 1999 Kocaeli Earthquake. It is thought that a Marmara Earthquake that will affect Istanbul will occur on one or more of the central segments that have not yet broken.

Due to its earthquake hazard, population size, building inventory stock and economic characteristics, Istanbul has become a region where earthquake risk should be determined as soon as possible. Seismic hazard studies of a possible earthquake and the extent to which settlement centers can be affected are tried to be analyzed by earthquake scenarios [2]. The map showing the risky earthquake zones for Istanbul is shown in Figure 1.

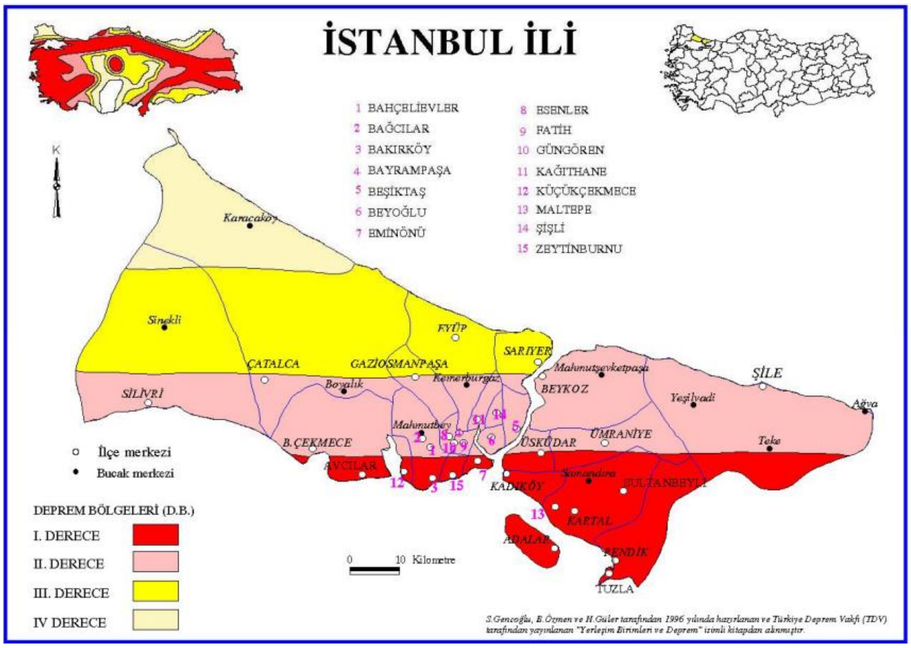

Figure 1: Istanbul Earthquake Zones (Source: [2])

Adalar district consists of 9 islands in Istanbul Province and its distance to the city center is 30 km. Kartal and Maltepe districts are the closest neighboring districts to Adalar district. This district has five neighborhoods: Burgazada, Heybeliada, Kınalıada, Maden and Nizam. According to 2019 TURKSTAT data, the population of the district is 15,238. There are 3,584 houses in the district before 1980. In addition, there are 6,155 houses with 1-4 floors and 538 houses with 5-8 floors, which make up 96%.

3. Literature Review

This study addresses the issue of assigning and scheduling search and rescue teams in disaster management, and the literature review on the related topic is presented in this section. The studies reviewed for the problem addressed in this study are summarized in Table 1.

Table 1: Literature Review

Author	Goal	Method
[3]	Assignment during the search and rescue period	Dynamic optimization, simulated annealing and tabu search
[4]	Planning rescue units and assigning units to incidents	Linear optimization, Monte Carlo based heuristic solution
[5]	Assigning and scheduling rescue units	Complex integer programming, GRASP metaheuristic approach
[6]	Allocating and scheduling rescue units under uncertainty	Biased random-key genetic algorithm
[7]	Assign rescue and medical units and allocate medical units to casualties at incident scenes	Optimization model proposal
[8]	Assigning teams	Multi-objective optimization
[9]	Assign rescue units in a multi-disaster area	Optimization model proposal
[10]	Assignment and scheduling of rescue units with fatigue effect	Three metaheuristic algorithms and TOPSIS
[11]	Assigning and scheduling rescue units	Complex integer programming and GRASP metaheuristic
[12]	Team planning taking into account the characteristics of the rescue team	Non-dominated sorting genetic algorithm and fuzzy logic method
[13]	Assignment and scheduling of recovery units with fatigue effect and withdrawal time	Multi-objective complex integer programming, Lp-metric method and two metaheuristics
[14]	Assignment and scheduling of rescue units with learning effect	Bi-objective complex integer linear programming
[15]	Duty assignment of rescuers	Agent-based simulation
[16]	Assignment and schedule of fatigue-impact recovery units	Two-objective complex integer programming
[17]	Search and rescue resource deployment planning	Complex integer programming
[1]	The problem of dispatching rescuers to multiple disaster areas	Dempster-Shafer theory with evidence-based best-worst method
[18]	Minimize the weighted completion time of rescue operations	Fuzzy robust optimization, hybrid metaheuristic algorithm
[19]	Assigning rescuers by calculating their synergy rating, fitness for duty rating and rescue time satisfaction rating	Optimization model proposal
[20]	Assignment of search and rescue and psychosocial support teams	Goal programming
[21]	Scheduling search and rescue teams to disaster districts	Goal programming
[22]	Scheduling search and rescue and psychosocial support teams to disaster areas	Goal programming
[23]	Scheduling search and rescue teams to disaster districts	Goal programming
[24]	Formation of search and rescue teams	Goal programming
[25]	Scheduling psychosocial support teams	Goal programming
[26]	Assignment of search and rescue teams	Goal programming

The goal programming method used in the considered problem has been widely used in the literature to solve many problems. [27] addressed the ergonomic staff scheduling problem in the retail sector with goal programming and AHP. [28] conducted a literature review on scheduling and planning in service systems with goal programming. [29] utilized goal programming and the ANP method in task-based personnel shift scheduling problems. [30] formulated the monthly staff assignment and scheduling problem during the pandemic period with the goal programming method. [31] addressed the operating room scheduling problem using constraint and goal programming methods. [32] used the goal programming method for shift scheduling of male and female security personnel. [33] addressed the ergonomic staff scheduling problem for female staff working in the textile industry with goal programming and the REBA method.

4. Application

The Adalar district of Istanbul Province, which will be affected by the expected Great Marmara Earthquake, which scientists have been discussing in recent years, has been taken as the place of application. The reason for considering the Adalar district, which will be significantly affected in population density, is to prevent a great tragedy due to the expected Marmara Earthquake. In this context, a sample planning study is presented on the problem of assigning search and rescue teams to disaster areas. The flowchart of the problem is given in Figure 2.

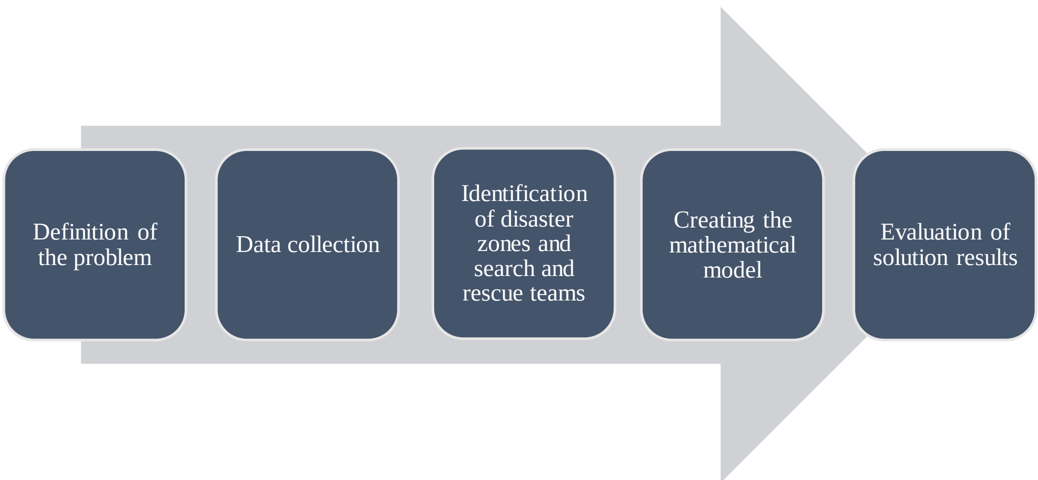

Figure 2: Flow Chart of the Problem

4.1. Problem Definition

This study addresses the problem of assigning teams to very heavily damaged buildings by considering the Adalar district, which will be affected by the Great Marmara Earthquake. The study is continued by using the 7.5 magnitude night earthquake scenario of the Main Marmara Fault, which has yet to be broken recently, included in the Istanbul Province Adalar District Possible Earthquake Loss Estimations Booklet. The data used in the study were the number of very heavily damaged buildings on a neighborhood basis calculated by the risk analysis module of the ELER software. To solve the problem, a mathematical model was created with the goal programming method, taking into account the number of building floors. The model was solved with the IBM ILOG program.

4.2. Data Collection

The data used in this study are listed below.

- ✓ Adalar district earthquake scenario
- ✓ The number of damaged buildings was calculated with ELER software
- ✓ Neighborhood-based building floor numbers
- ✓ Information about search and rescue teams

4.3. Identification of Disaster Zones and Search and Rescue Teams

When the results of the estimates of the number of damaged buildings in the Adalar district are examined, it is seen that five neighborhoods that require search and rescue operations were severely damaged. These neighborhoods are Burgazada, Heybeliada, Kınalıada, Maden and Nizam. In total, 413 buildings were severely damaged.

4.4. Creating the Mathematical Model

4.4.1. Goal Programming

The goal programming method, used to solve many problems in the literature, simultaneously provides conflicting objectives. There are multiple objectives in this method. The method achieves the desired objective by minimizing the deviation variables that express the deviations of the constraints from the objectives [34], [35]. The mathematical form of the method is as follows.

$x_j: j. decision\ variable$

$a: decision\ variable\ coefficient\ parameter$

$r: goal\ constraint\ right\ side\ value\ parameter$

$d_i^+: i. positive\ deviation\ value\ of\ goal$

$d_i^-: i. negative\ deviation\ value\ of\ goal$

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

$$\sum_{j=1}^{m} a * x_j - d_i^+ + d_i^- = r \tag{2}$$

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

Equation (1) is the objective function of the model. Equation (2) is the objective constraint of the model, where r is the desired right-hand side value. Equation (3) is the rigid constraint of the model; if it is not satisfied, the model is unsolvable.

4.4.2. Mathematical Model Created

Parameters

$n = number\ of\ teams$

$m = number\ of\ neighborhoods$

$i = team\ index \qquad i = 1,2, \dots, 330$

$j = neighborhood\ index \qquad j = 1,2, \dots, 5$

Decision variables

$$x_{ij} = \begin{cases} 1, if\ team\ i\ is\ assigned\ to\ neighborhood\ j. \\ 0, other\ situations \end{cases} \qquad \forall_{i,j}$$

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

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

$$\sum_{i=1}^{n} x_{i1} - d_{i1}^{+} + d_{i1}^{-} = 45 \tag{3}$$

$$\sum_{i=1}^{n} x_{i2} - d_{i2}^{+} + d_{i2}^{-} = 75 \tag{4}$$

$$\sum_{i=1}^{n} x_{i3} - d_{i3}^{+} + d_{i3}^{-} = 50 \tag{5}$$

$$\sum_{i=1}^{n} x_{ij} - d_{i4}^{+} + d_{i4}^{-} = 80 \qquad j = (4, 5) \tag{6}$$

$$min\, Z = \sum_{i=1}^{n} (d_{i1}^{+} + d_{i1}^{-} + d_{i2}^{+} + d_{i2}^{-} + d_{i3}^{+} + d_{i3}^{-} + d_{i4}^{+} + d_{i4}^{-}) \tag{7}$$

$$x_{ij} = 0\ veya\ 1 \ \ \forall_{i,j} \tag{8}$$

$$d_{i1}^{+}, d_{i1}^{-}, d_{i2}^{+}, d_{i2}^{-}, d_{i3}^{+}, d_{i3}^{-}, d_{i4}^{+}, d_{i4}^{-} \geq 0 \qquad \forall_i \tag{9}$$

Equation (1) refers to assigning at least 1 team to each neighborhood and Equation (2) refers to assigning each team to at most one neighborhood. Equations (3)-(6) are the objective constraints of the problem. Equation (3) aims to assign 45 teams to the Burgazada neighborhood, Equation (4) aims to assign 75 teams to the Heybeliada neighborhood, Equation (5) aims to assign 50 teams to the Kınalıada neighborhood, Equation (6) aims to assign 80 teams to the Maden and Nizam neighborhoods. Equation (7) is the objective function of the problem. Equations (8)-(9) are the sign constraints of the problem's decision variables.

4.5. Evaluation of Solution Results

According to the solution results, 45 search and rescue teams were assigned to the Burgazada neighborhood, 75 to the Heybeliada neighborhood, 50 to the Kınalıada neighborhood, 80 to the Maden neighborhood, and 80 to the Nizam neighborhood. All 330 search and rescue teams considered in the problem were assigned to the disaster areas and all objective constraints were met. The solution results are given in Figure 3.

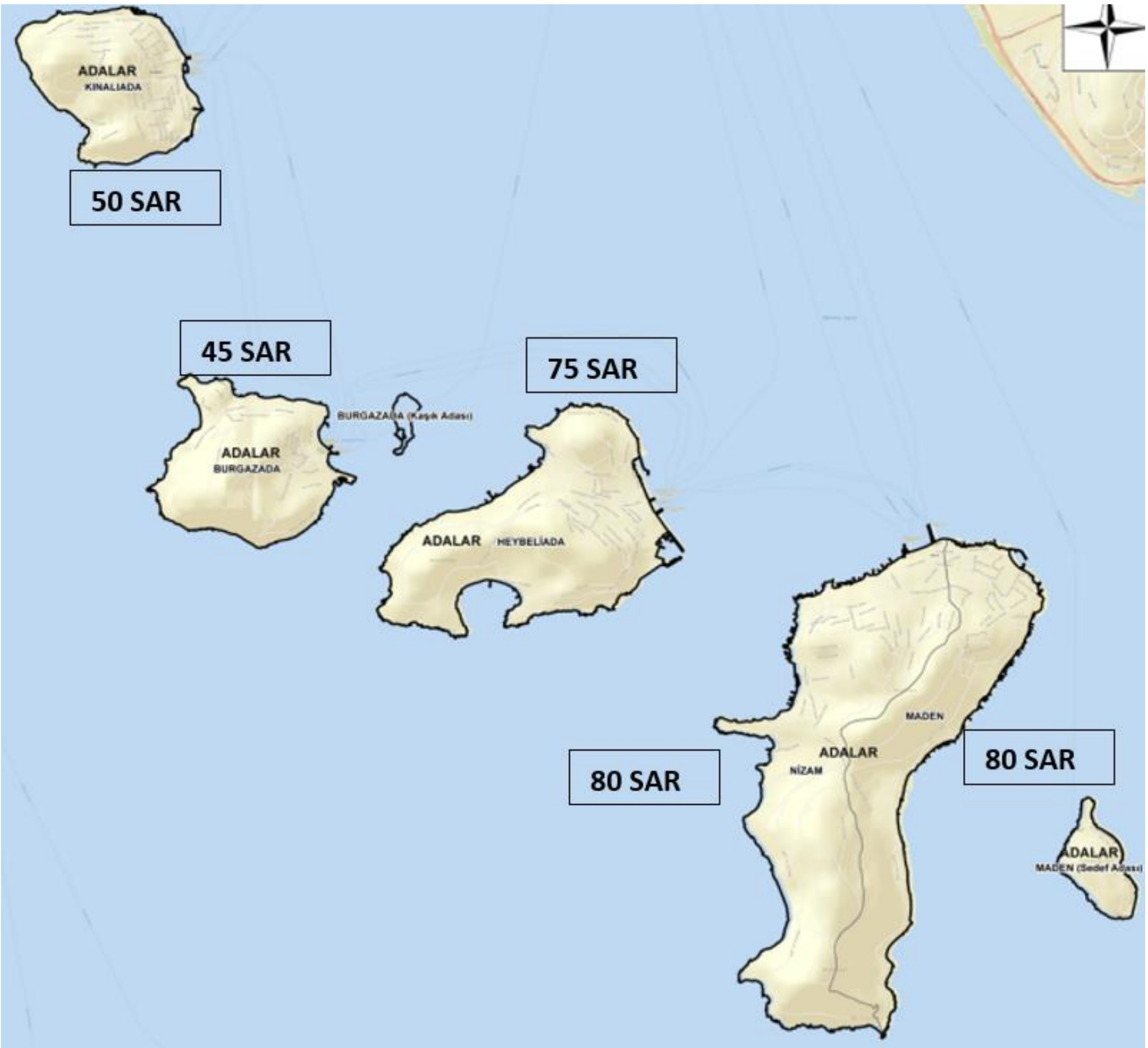

Figure 3: Solution Results (SAR: Search and Rescue Teams)

5. Conclusions And Recommendations

It aims to minimize losses and damages by assigning teams to disaster areas with a deterministic earthquake scenario. Thanks to the results obtained from the problem, it will plan which number of teams should go to which neighborhood in the Adalar district, which is predicted to be heavily damaged in the expected Marmara earthquake. It will support decision-makers by eliminating the chaos that may occur during the disaster. Thus, the response phase will start as soon as possible. 413 buildings in 5 neighborhoods in Adalar district are severely damaged. Looking at the solution results obtained, all of the search and rescue teams available in the targeted numbers were assigned to the neighborhoods of Adalar district.

In this study, the teams were assigned assuming the destruction would occur only in Adalar district. In future studies, the mathematical model created by including other districts where the destruction will occur in the problem can be used again.

Contribution of Researchers

All researchers have contributed equally to writing this paper.

Conflicts of Interest

The authors declare no conflict of interest.

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