Assessing the Emergency Assembly Areas Using Maximum Coverage Location Analysis: A Case of Gaziantep University

Eren Özceylan[1](✉) and Cihan Çetinkaya[2]

[1] Industrial Engineering Department, Gaziantep University, 27100 Gaziantep, Turkey
erenozceylan@gmail.com

[2] Department of Management Information Systems, Adana Alparslan Turkes Science and Technology University, 01200 Adana, Turkey
ccetinkaya@atu.edu.tr

Abstract. Emergency assembly areas (EAAs) are safe areas where the people can gather away from the dangerous area in order to prevent the panic that will take place until the temporary shelter centers are ready after disasters and emergencies. Determination of a suitable site for an EAA is crucial to decrease the negative impacts of disasters. There are a few criteria to be considered while finding a place for an EAA, e.g. assembly points should be located at a safe distance away from the danger (building, fire), they must be easily accessible, and finally they must be big enough to accommodate all potential victims. To solve this problem scientifically, the aforementioned conditions should be modeled as a maximum coverage location (MCL) problem. In this paper, the EAAs in Gaziantep University campus are discussed and evaluated. To do so, the 32 current points are considered as source nodes, and 65 buildings are considered as demand nodes. The covered population who are evacuated from buildings is maximized under different travel distance limits. An integer programming formulation is applied to evaluate the current EAAs and the suitability of existing signs is discussed. As a result, it has been determined that eight current EAAs are not suitable. According to another result, everyone can reach the remaining 24 EAAs within 196 m.

Keywords: Emergency assembly area · Evacuation · Integer programming · Location analysis · Maximum coverage location

1 Introduction

Emergency assembly areas (EAAs) are pre-determined areas, to be used in case of emergency situations. They provide a safe area for potential disaster victıms to stand during the period for emergency aid. These safe areas also aim to prevent panic and ensure healthy information exchange in the period until temporary shelter centers are ready after disasters.

Not every empty space is suitable for EAAs. Various criteria are evaluated together while determining these assembly points. EAA determination criteria can be summarized

A. Hamrol et al. (Eds.): MANUFACTURING 2022, LNME, pp. 36–46, 2022.
https://doi.org/10.1007/978-3-031-00218-2_4

as; being away from secondary dangers, being accessible and finally having adequate place for keeping the population safe [1].

According to Turkish Disaster and Emergency Management Presidency strategic plan [2]: (*i*) increasing the effectiveness of coordination in disaster and emergency management and (*ii*) managing the processes during and after disasters in the most effective way are listed among the main objectives for disaster preparedness plan. In this context, determining the EAAs in strategic locations is crucial.

The problem area of this paper, namely Gaziantep city is the ninth most crowded city in Turkey [3]. In addition, as can be seen in Fig. 1, the city is determined among the most earthquake risky cities of the country.

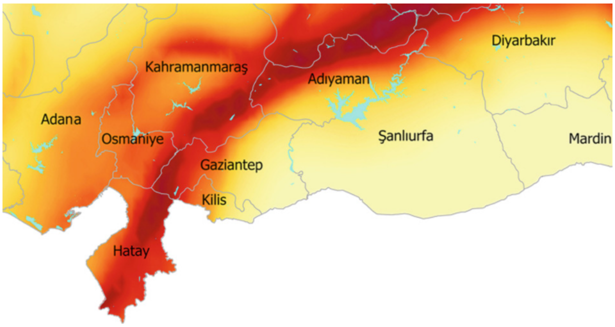

Fig. 1. The earthquake risk map of Gaziantep and its region [2].

Therewithal, the University of Gaziantep has almost 50 thousand people including students, academicians and staff in its campus, being among the most crowded institutions in the region. Thus it is important to make an emergency plan for the campus.

In this study, the EAAs in Gaziantep University campus are investigated. Firstly, the 32 current assembly points are considered as source, and 65 university buildings are considered as demand nodes. The number of potential victims is maximized regarding alternative distance limits. For the solution, an integer programming formulation is proposed to evaluate the current EAAs and offer new locations.

The outline of the paper is as follows; the next section examines the literature on MCL problems and defines how the proposed paper will fill the gap. The third part defines the proposed methodology and the fourth part includes the case study and analysis. In the fifth part, the summary of the paper is given and future directions are explained.

2 Literature Review

Since emergency management is a very important topic, there are a lot of papers with different approaches to similar problems. In this part, the emergency management studies that use the MCL analysis are summarized.

Araz et al. [4] proposed a multi-objective MCL model to solve the emergency service vehicles location problem. They aimed to determine the best locations for a group of vehicles while optimizing the service levels. For the solution of the problem, they proposed lexicographic multi-objective linear programming and fuzzy goal programming approaches. To prove the applicability of the proposed model, they provided numerical examples by using different solution approaches.

Balcık and Beamon [5] considered facility location problem for humanitarian relief chain. They developed a model to determine the number and locations of distribution centers and the total amount of supplies to be kept at each center. They formed the problem as a variant of the MCL model that integrates inventory decisions and facility locations. The computational experiments were conducted by using GAMS/CPLEX and they illustrated the efficiency of the proposed model on a real case problem. As a result, the effects of pre & post disaster relief funding on system's performance, especially on proportion of demand and response time were satisfied.

Yin and Mu [6] examined a modular capacitated MCL problem and formulated to allow different capacity levels for each facility at potential sites. To optimally site emergency vehicles, they considered allocations of the demands in addition to the covering standard. Two scenarios were discussed in the model: the facility constrained model that fixes the total number of facilities, and non-facility constraint model. In addition, they also applied spatial demand representation in the analysis and discussion. Finally, as a case study in the State of Georgia, Geographic Information System and optimization software packages were used together to site the ambulances optimally for the Emergency Medical Services.

Chanta et al. [7] focused on ambulance location problem to optimize the level of ambulatory services provided to patients in rural or urban areas. They modified the MCL models by proposing three bi-objective covering location models. The multi-objective problem was solved by the ε-constraint method. The obtained results were provided by using the data from Hanover County fire department, Virginia. A sensitivity analysis was applied to provide an insight on how the zone classification affects the solution. It was reported that the proposed method was effective and could help to reduce disparities in service levels in emergency management.

Zhang et al. [8] employed uncertainty theory to address the emergency service facility location problem under uncertainty. They made use of the uncertain location set covering model and also they examined MCL problem again in uncertain environment. In addition, they modeled the MCL problem by using different approaches, namely, the (α, β)-MCL model and the α-chance MCL model. Finally, their approaches were illustrated by a case study in Sichuan, China.

Paul et al. [9] tried to analyze the effectiveness of the current and optimal locations of emergency management assets that belongs to the Department of Defense in United States. They formulated a multi objective MCL problem and they developed a set of non-inferior solutions by making use of the "ε-constraint" method. By doing so, they offered several Pareto optimal decisions to the decision makers. They highlighted that, as a result of their case study; by the relocations determined by the model, additional 45 million people could be covered.

Li et al. [10] examined the ambulance location problem in emergency medical service by proposing a MCL model. They used improved double standard model for the solution of the problem. A real case study was conducted by using the emergency medical service data in Shanghai, China. It is reported that the proposed model improved the service levels and allocation of the ambulances.

Zhang et al. [11] examined the multimodal facility location problem in humanitarian logistics. The multimodality rooted in, landside, airside, air-ground transshipment and air-ground combined transport. They proposed a two-stage MCL model for the problem. A solution algorithm was proposed and computational experiment was conducted by using a Java platform and CPLEX solver. They validated the proposed model's efficiency in a case study of Beijing, China. It was reported that the proposed approach was suitable for large-scale disaster rescue.

Yang et al. [12] proposed a MCL problem often confronted in natural disasters. Their aim was to optimize the locations of the communication hub centers of the self-organizing mobile network that is established in fields not receiving signal. They formulated the problem with two mixed-integer mathematical linear programming models and two hierarchical objective functions; the shortest moved distance and the maximum coverage. A new linearization method was used to linearize and solve the proposed models optimally. In addition, they provided a MILP-based heuristic approach to solve larger problems. As the result of experimental analysis, they summarized that the proposed models could find good solutions and were applicable for the emergency rescue scenes.

Bahrami and Ahari [13] examined the MCL problem for emergency services in Iran. They formulated the proposed problem by M (t)/M/m/m queuing system which try to minimize the number of victıms waiting in the queue for receiving services. The obtained results showed that the GAMS software was not able to solve large problems. So they proposed an NSGA-II algorithm to solve larger problems. They demonstrated the applicability of the model in real case study that took place in a metropolitan city in Iran.

Alizadeh and Nishi [14] presented a hybrid covering model that exploits the set covering and MCL problems. The problem that they took into account was locating the first aid centers in humanitarian logistic services in Japan. The dynamic set covering location problem determined the locations of the facilities and assigned the facilities and allocated demand points via dynamic modular capacitated MCL problem. They validated the model by a case study in Japan and the results were compared to other possible combined problem versions. As a summary, it was reported that their model provided better coverage percentages when compared to other covering models.

This paper will fill the gap in the literature by proposing MCL problem while modeling the distance, accessibility and expanse criteria. Also solving a real case problem of a very crowded institution namely Gaziantep University is another contribution of the paper.

3 Methodology

In this paper, the current locations of EAA signs are evaluated and also new locations for additional signs are discussed. To do so, one of the well-known location-allocation models namely maximum coverage location (MCL) model is used in this study.

The MCL problem considers the objective of locating a given number of facilities (EAA signs) to maximize the covered number of demand nodes (buildings include

students, staff, and academicians) and demand nodes are expected be covered entirely if nodes are in the range of critical distance of the facility (an EAA sign), otherwise it is assumed to be not covered [15]. The optimal result of a MCL problem depends on pre-decided critical distance, decision on a critical distance value without altering coverage may lead "fully covered" to "not covered" [16]. The formulation of MCL model applied is given as follows [17]:
Sets and indices

$i \in I$, set of demand notes (buildings),
$j \in J$, set of candidate facilities (sites of EAA signs),
S, the distance beyond which a demand point is considered "uncovered",
N_i $\{j \in J/d_{ij} \leq S\}$ the nodes j that are within a distance of S to node i.

Parameters

P number of facilities
d_{ij} shortest distance between locations i, j,
a_i population (students, staff, and academicians) to be served at demand node i.

Decisions Variables
x_j is 1 if a facility sited at the jth node ($j \in J$); 0 otherwise,
y_i is 1 if node i is covered by one or more facilities stationed within S; 0 otherwise.

$$\text{Objective Function maximize} \sum_{i \epsilon I} a_i y_i \tag{1}$$

subject to

$$y_i \leq \sum_{j \epsilon N_i} x_j, \tag{2}$$

$$\sum_{j \epsilon J} x_j = P, \tag{3}$$

$$y_i, x_j \epsilon \{0, 1\} \quad \forall i \epsilon I, \forall j \epsilon J. \tag{4}$$

The objective function (1) is maximizing the sum of covered population in the sets in which they are covered. Constraint (2) allows y_i to equal 1 only when one or more EAA signs are established at sites in the set N_i (that is, one or more signs are located within S distance units of demand point i). Constraint (3) states that exactly p amount of signs are to be located. The binary restriction is shown in Constraint (4).

4 Case Study

The campus of Gaziantep University is selected as the study area in this paper. The campus has a total of 2,248,301 square meters of open space. The 65 buildings (faculties,

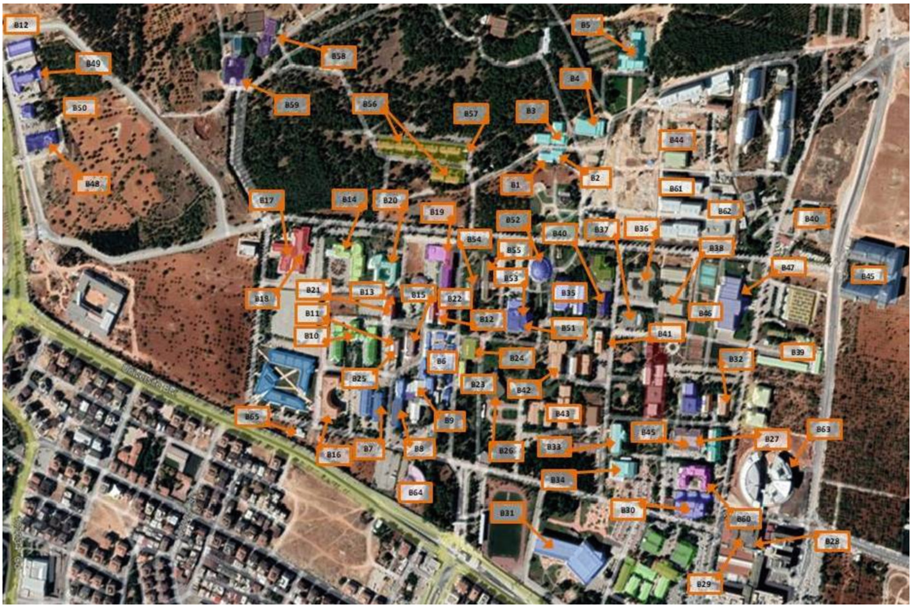

Fig. 2. The locations of demand nodes (buildings).

departments, administration offices and etc.) are considered as demand points and shown (B1 to B65) in Fig. 2.

There are 32 EAA signs in the main campus at the time of this study. The locations of current signs (EAAs) are shown in Fig. 3. One of the current signs namely EAA24 (written in Turkish) is shown in Fig. 4.

Fig. 3. The locations of current EAA signs.

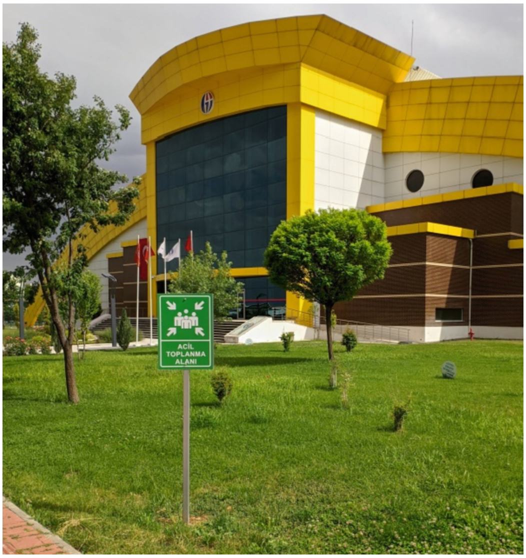

Fig. 4. The picture of EAA24 (written in Turkish).

To find dangerous zones, the heights of buildings are calculated. Magnitude of buffers is determined via buildings' heights and multiplying them by 1.5 [18]. These zones are debris coverage zones and EAAs must be stay away from debris. If a building is collapsed in an earthquake, the effect area of that building is shown in the Fig. 5. According to the Fig. 5, it is found that eight of the current EAA signs are located in the dangerous zones. Eight signs (EAA4, 11, 13, 16, 17, 24, 27, and 31) within the impact area are also shown in Fig. 5. It means that the mentioned signs are not located properly.

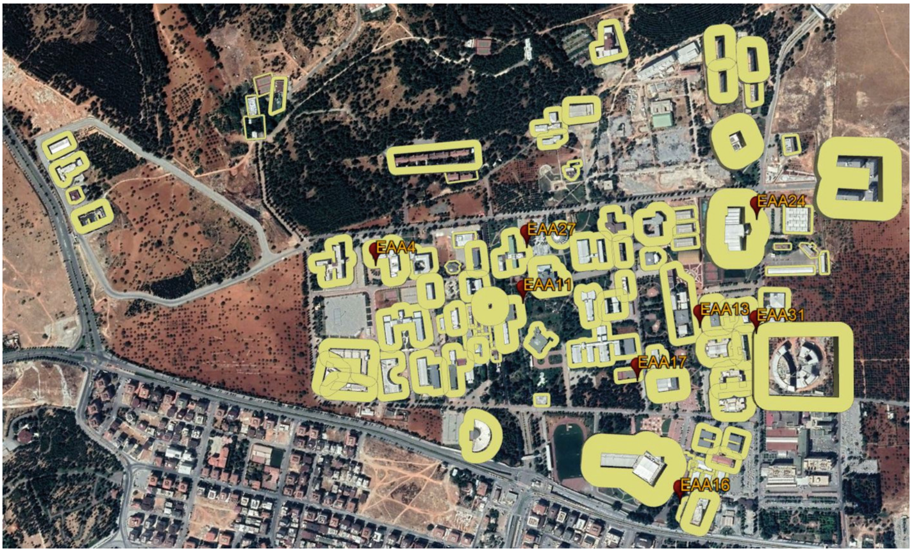

Fig. 5. The dangerous zones of buildings if they are collapsed.

To re-locate the missing signs and evaluate current signs, suitable areas where signs to be placed are determined. The blue areas that cover 8,002 square meters show potential available locations (see Fig. 6). As it is known, 0.75 square meter space is required per person in the assembly areas [18]. Therefore, a total of 10,669 people can gather in the areas shown in blue. University's main campus population is almost 50,000 including students, academicians, and staff. But not all these people are in the buildings at the same time. Therefore, the blue areas can cover one-fifth of the total population. Figure 6 also shows the proper 24 (32 – 8 = 24) current signs.

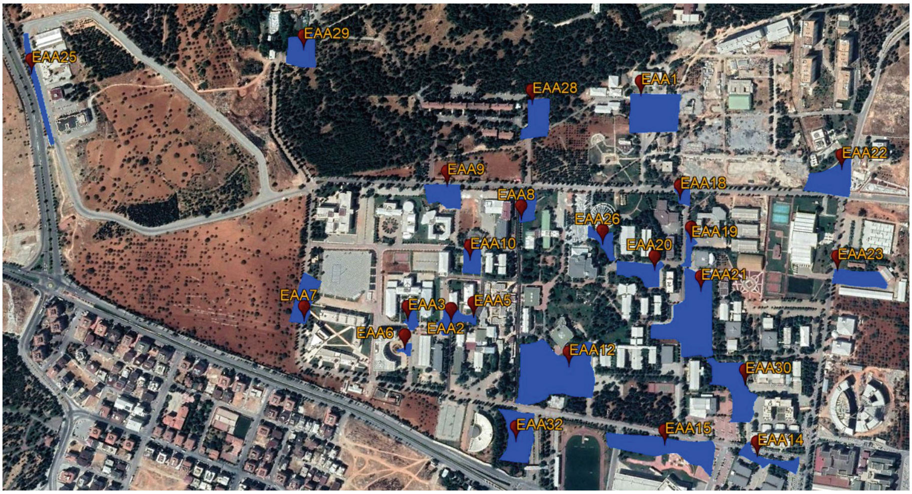

Fig. 6. Available emergency assembly areas.

At this stage of the study, maximum coverage model is applied. To apply the model, 24 signs are considered as a facility. Therefore, p is taken as 24. There are 65 buildings. 10,669 people are distributed to those 65 buildings (demand nodes) (see Table 1).

The mathematical model (Eqs. 1–4) is written in LINGO 14.0 using the data above. In the model, different coverage distances (S) are considered such as 25, 50, 75, 100, 125, 150, 175 and 196 m. The results of the model are given in Table 2 including the information of covered/uncovered buildings and population.

According to the Table 2, all people (10,669 people) can reach at least one EAA sign in 196 m. However, decreasing the coverage distance limit also decreases the number of covered people and buildings as expected. For instance, only 25.06% of people can reach an assembly area in 25 m. It must be noted that 24 of 32 current signs are considered in this analysis. Eight of them are located in unsuitable areas. Although 196 m is acceptable to reach an assemble area, all population can be covered in a shorter coverage distance if the eight idle signs are re-located.

Table 1. Population in buildings.

Building	Population	Building	Population	Building	Population	Building	Population
B1	15	B18	260	B35	12	B52	1
B2	6	B19	148	B36	295	B53	25
B3	3	B20	224	B37	15	B54	210
B4	4	B21	771	B38	5	B55	3
B5	323	B22	1	B39	5	B56	175
B6	1	B23	12	B40	5	B57	1
B7	101	B24	21	B41	342	B58	64
B8	121	B25	20	B42	218	B59	72
B9	68	B26	431	B43	432	B60	1
B10	531	B27	415	B44	14	B61	161
B11	149	B28	764	B45	25	B62	8
B12	4	B29	1532	B46	27	B63	5
B13	5	B30	595	B47	13	B64	4
B14	764	B31	1	B48	25	B65	1
B15	1	B32	17	B49	25		
B16	222	B33	190	B50	25		
B17	133	B34	1	B51	1	Total	10,669

Table 2. Results of MCL problem.

Distance limit	Covered population ratio	# of covered buildings	Uncovered buildings
25 m	25.06%	18	B2, B3, B5, B6, B7, B8, B4, B5, B17, B18, B19, B20, B21, B23, B24, B26, B27, B29, B31, B32, B33, B34, B36, B38, B39, B40, B41, B43, B44, B46, B47, B48, B49, B50, B51, B54, B55, B56, B57, B58, B59, B60, B61, B62, B63, B64, B65
50 m	66.12	37	B2, B5, B6, B14, B17, B24, B26, B27, B32, B34, B36, B38, B39, B40, B44, B46, B47, B48, B49, B50, B51, B54, B56, B57, B58, B62, B63, B65
75 m	76.38	50	B5, B14, B17, B24, B26, B32, B38, B39, B40, B46, B56, B57, B62, B63, B65
100 m	76.97	55	B5, B14, B17, B26, B32, B56, B57, B62, B63, B65
125 m	84.08	61	B5, B14, B32
150 m	84.20	63	B5, B14
175 m	91.36	64	B5
196 m	100.00	65	None

5 Conclusion

The EAAs are used in case of an emergency and the victims are kept there until partially or completely evacuation. In most of the governmental institutions, these assembly points are pre-determined and it is very important to inform the people about these points. The EAAs need to be clearly signposted to make it obvious; also these signposts can prevent others from parking there or dumping items to the area. Since our country – Turkey– had many disasters especially earthquakes for years, the Disaster and Emergency Management Presidency pays attention to the disaster education and preparedness. The year 2021 was determined as Disaster Education Year [19]. One of the most important objectives of this theme is determining the EAAs scientifically.

In this paper, the EAAs in Gaziantep University campus are taken into account. The distance, accessibility and the expanse of the area are chosen as the most important issues that affects the EAA location problem. Thus these conditions are modeled as a MCL problem. Current 32 assembly points in the campus are chosen as source nodes, and 65 buildings in the campus are considered as demand nodes. The maximization of covered population (students, academicians and staff) is aimed considering different travel distances. An integer programming formulation is applied to evaluate the current EAAs. As a result, eight of the 32 signs are found as unsuitable because they are located in the dangerous area. Therefore, the locations of eight signs should be changed. According to the model, the remaining 24 signs can cover all the population in 196 m. Decreasing the reach distance from 196 m to 25 m also decreases the covered population by 75%.

Consequently, a scientific approach is proposed for using in emergency management in the university campus. The results of the paper can be used by university administration and policy makers. For the future studies, geographic information system-based multi-criteria decision making techniques can be used together for determining the additional EAAs.

References

1. DEMP: Disaster and Emergency Management Presidency (2021). https://www.afad.gov.tr/toplanma-alanini-ogren-ki-canin-sag-olsun. Accessed 24 Nov 2021
2. DEMP: Institutional Reports: 2021 Performance Program (2021) https://www.afad.gov.tr/kurumsal-raporlar. Accessed 24 Nov 2021
3. TSI: Turkish Statistical Institute, Address Based Population Registration System Results (2021). https://data.tuik.gov.tr/Bulten/Index?p=Adrese-Dayali-Nufus-Kayit-Sistemi-Sonuclari-2020-37210. Accessed 24 Nov 2021
4. Araz, C., Selim, H., Ozkarahan, I.: A fuzzy multi-objective covering-based vehicle location model for emergency services. Comput. Oper. Res. **34**(3), 705–726 (2007)
5. Balcık, B., Beamon, B.M.: Facility location in humanitarian relief. Int. J. Logist. Res. Appl. **11**(2), 101–121 (2008)
6. Yin, P., Mu, L.: Modular capacitated maximal covering location problem for the optimal siting of emergency vehicles. Appl. Geogr. **34**, 247–254 (2012)
7. Chanta, S., Mayorga, M.E., McLay, L.A.: Improving emergency service in rural areas: a bi-objective covering location model for EMS systems. Ann. Oper. Res. **221**, 133–159 (2014). https://doi.org/10.1007/s10479-011-0972-6

8. Zhang, B., Peng, J., Li, S.: Covering location problem of emergency service facilities in an uncertain environment. Appl. Math. Model. **51**, 429–447 (2017)
9. Paul, N.R., Lunday, B.J., Nurre, S.G.: A multi objective maximal conditional covering location problem applied to the relocation of hierarchical emergency response facilities. Omega **66**, 147–158 (2017)
10. Li, R., Su, Q., Wang, Q., Wu, W.: A maximal covering location model of ambulances in emergency medical service. In: 15th International Conference on Service Systems and Service Management Proceedings, pp. 1–5. IEEE, Hangzhou (2018)
11. Zhang, M., Zhang, Y., Qiu, Z., Wu, H.: Two-stage covering location model for air ground medical rescue system. Sustainability **11**, 3242 (2019)
12. Yang, P., Xiao, Y., Zhang, Y., Zhou, S., Yang, J., Xu, Y.: The continuous maximal covering location problem in large-scale natural disaster rescue scenes. Comput. Ind. Eng. **146**(2), 106608 (2020)
13. Bahrami, I., Ahari, R.M.: A maximal covering facility location model for emergency services within an M(t)/M/m/m queuing system. J. Model. Manag. **16**(3), 963–986 (2020)
14. Alizadeh, R., Nishi, T.: Hybrid set covering and dynamic modular covering location problem: application to an emergency humanitarian logistics problem. Appl. Sci. **10**, 7110 (2020)
15. Karasakal, O., Karasakal, E.: A maximal covering location model in the presence of partial coverage. Comput. Oper. Res. **31**, 1515–1526 (2004)
16. Frade, I., Ribeiro, A.: Bike-sharing stations: a maximal covering location approach. Transp. Res. Part A Policy Pract. **82**, 216–227 (2015)
17. Church, R., ReVelle, C.: The maximal covering location problem. Pap. Reg. Sci. Assoc. **32**, 101–118 (1974). https://doi.org/10.1007/BF01942293
18. Spyridaki, P., Papadopoulou, I.D., Grigoriadis, V.N., Tziavos, I.N., Savvaidis, P.: Methodology for identification of emergency assembly areas and road network in cities using geographic information systems tools. In: International Multidisciplinary Scientific GeoConference Proceedings, Surveying Geology and Mining Ecology Management, Sofia, Bulgaria, pp. 135–142 (2009)
19. Bozkurt, Ö.: Disaster awareness culture and 2021 Turkey disaster education year (in Turkish). Turk. Adm. Assoc. **199**, 51–57 (2021)