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Introducing a new Model for Locating the Location of Firefighting Forces Based on Fuzzy Region and Nondominated Sorting Genetic Algorithm

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Abstract

The establishment of fire stations is considered an essential part of the security of any city. At the time of an accident, the location of fire stations is essential for timely and quick relief. The delay in providing aid causes irreparable damage to the life and property of the city's people, and the correct location of fire stations can prevent such incidents from happening, which is necessary to achieve this goal. It is systematic and integrated based on a suitable model. Therefore, in this research, a suitable model for locating the position of firefighting forces based on fuzzy logic and mutated genetic algorithm is proposed, which has two objective functions: one for optimizing the urban coverage and the other for optimizing Building the number of fires stations. The goal is to deploy stations in such a way as to create maximum urban coverage, and on the other hand, considering the cost of deploying each station, the method seeks to reduce the number of stations. The criteria needed for the stations' location have been examined, including the distance from the existing fire station. S the distance from the areas at risk of earthquakes, the high population density, the density of wooden buildings, the proximity to the roads—the main and density of hazardous materials facilities., the data set of fire stations in Istanbul city was used, to check the results and simulation in this research. This data set contains two parts, one of which contains information about the location of the stations, which has 124 data, and the other contains related information to the areas where the fire occurred and has 107 data. In this research, five scenarios were set, the first scenario of two parameters, the second scenario of three parameters, the third, fourth, and fifth scenarios of four parameters and their influence on the choice of the parent were investigated, and the results showed that the best solution is It is obtained that both goals have the same weight in the scenarios. It happens when the number of stations reaches the desired level. In fact, by increasing the number of stations to the appropriate size, the urban coverage amount reached the desired results.

Keyword: Location Location, Deployment of Fire Brigades, Fuzzy Logic, Mutated Genetic Algorithm.

1. Introduction

Creating new urban facilities requires a detailed study of how to establish them in different city areas properly. The first essential point to properly allocate urban facilities is to choose the optimal location according to different and sometimes conflicting conditions. This issue becomes important when considering critical factors, such as saving human lives. Therefore, the optimal selection of fire stations is considered a fundamental issue due to the importance of the lives of people who are at risk. The existence of cities is generally mixed with serving and providing services to the residents within the legal and sacred limits of the cities. Aid utilities are essential compared to other urban services due to their activities. Fire stations, such as places for establishing and waiting for fire and rescue vehicles, are among the most vital service centers in cities, which play an essential role in ensuring the safety and comfort of citizens and the development of cities. Therefore, locating fire stations, determining the number of stations to cover the city and provide services to the citizens according to the city's characteristics and features and the existing financial and logistical capacity, and predicting future facilities' development are vital measures. It is necessary for this context. The traditional location of these stations has mostly been subject to land ownership and management preferences. Among the disadvantages of examining them in the traditional format are the inability to use all the effective parameters simultaneously and being time-consuming. However, due to the difference in the type and nature of cities in terms of land prices, space compression, population density, and the city's structure, the need to refine the indicators are evident and neglecting these factors in locating causes a significant amount of waste. Material resources and the loss of many environmental resources cause heavy damage to people and urban management. Therefore, information technology, especially the spatial information system, is necessary to analyze a large amount of data. The places considered as outputs should respond as much as possible to future changes in the dynamic urban system and with flexibility. It is necessary to direct the city's safety services (Khanahmadi, M., Arabi, M., Vafaienejad, A., & Rezaiean, H., 2014).

The rapid expansion of cities has brought new challenges for urban firefighting security. The increased frequency of fires has seriously threatened the lives, property, and safety of people living in cities. Extinguishing fire in cities is challenging, and the optimal spatial arrangement of fire stations is vital for fire safety (Han, B., Hu, M., Zheng, J., & Tang, T., 2021).

Fires in most big cities have caused many casualties due to heavy traffic, access problems, and long fire brigade immediate response time. Therefore, the location of fire stations is essential to those stations' ability to deal with city fire and crisis management. Determining where to establish a fire station and how many stations to build in an area are the most critical decisions that fire department officials and crisis management headquarters should address. In general, choosing the right location for the fire station has the following advantages for crisis management, which include the following:

• Shortening the distance between the fire station and the accident scene increases the reaction time efficiency.

• Minimal overlapping of fire station services for optimal use of station resources;

• They are helping to determine the appropriate number of stations in an area by considering a cost-benefit issue and reducing casualties due to road accidents and the costs of setting up and operating costs of the stations.

The set of investigations and analyses on fire incidents and how fire stations work shows significant limitations, challenges, and inadequacies in location selection and optimal performance. There are stations. These problems and challenges can be classified as follows:

• Non-compliance with the location and coverage radius of the stations with the potential foci of fire

• The disproportion of the spatial distribution of the stations with the requirements and urban context

• Inadequacy of spatial distribution of stations with time coverage standard

• A sufficient number of stations compared to both criteria of population and area of cities

Hence, there is a need for a multi-objective approach to solving the problem of locating fire stations instead of a single-objective approach. The primary purpose of the positioning is to prevent wasted costs on the one hand and guarantee the optimal efficiency of the stations in comparison with the urban system (Dey, A., Heger, A., & England, D., 2021). As a result of this research, the question is answered: Is it possible to provide a new model for locating the location of firefighting forces based on fuzzy logic and a mutated genetic algorithm?

2. Related Works

Dey et al. (2021): "Urban Fire Station Location Planning: A Systematic Approach using Predicted Demand and Service Quality Index." In this article, they propose a systematic approach to fire station location planning. They develop a machine learning model, based on Random Forests, for demand prediction and utilize the model further to define a generalized index to measure the quality of fire service in urban settings. their model is built upon spatial data collected from multiple sources. The efficacy of proper facility planning depends on the choice of candidates where fire stations can be located along with existing stations, if any. Also, the travel time from these candidates to demand locations must be taken care of to maintain fire safety standards. Here, they propose a travel time-based clustering technique to identify suitable candidates. Finally, they developed an optimization problem to select the best locations to install new fire stations. Based on integer programming, their optimization problem is built upon the maximum coverage problem. They present a detailed experimental study of their proposed approach in collaboration with the city of Victoria Fire Department, MN, USA. their demand prediction model achieves an actual positive rate of 70% and a false positive rate of 22% approximately. Using their approach, they aid Victoria Fire Department in selecting a location for a new fire station. They present detailed results on improvement statistics by locating a new facility, as suggested by their methodology, in the city of Victoria (Dey, A., Heger, A., & England, D., 2021).

Tatsuya et al. (2020): "An analysis of the optimum location of a fire department based on ambulance dispatch situation—A case study in Utsunomiya City." The purpose of this study is to analyze the optimum location of fire departments. This research aims to minimize the response time by confirming emergency services dispatched and absence situations. The analysis method calculates average response times using the optimization algorithm containing a dispatch simulation. We calculated the results by using actual past dispatch data. The results show that the median model shortened traveling distances by about 367m, and the simulation model shortened distances by about 438m compared to the current location. The purpose of this study is to analyze the optimum location of fire departments. The point of view of this research is to minimize the response time by confirming emergency services dispatched and absent situations (Suzuki, T., & Satoh, E., 2020).

Jing et al. (2019):" Location optimization of urban fire stations: Access and service coverage." Fire and rescue services are among the most critical public services governments provide to protect people, property, and the environment from fires and other emergencies. Efficient deployment of fire stations is essential to ensure timely response to calls for service. Given the geographic nature of such problems, spatial optimization approaches have long been employed in public facility location modeling along these lines. In particular, median and coverage approaches have been widely adopted to help achieve travel cost and service-coverage goals. This paper proposes a bi-objective spatial optimization model that integrates coverage and median goals in the service of demand areas. Based on the properties of derived objective functions, we presented a constraint-based solution procedure to generate the Pareto frontier, enabling the identification of alternative fire station siting scenarios. The developed model is applied to an empirical study that seeks to identify the best fire station locations in Nanjing, China. The results demonstrate the value of spatial optimization in assisting fire station planning and rescue resource deployment, highlighting important policy implications (Yao, J., Zhang, X., & Murray, A. T., 2019).

Quick response time in an emergency is critical to protect human lives. In fast-growing cities, fire departments can fall behind the standard response time due to cities' expansion. This research focuses on improving the response time to a city's emergency. A Non-linear Programming model is used to determine the locations of fire stations so that they can cover the maximum number of residents in terms of geographical area and population. The model is applied to Kingsville, Texas, to check the practicability. The research results indicate that optimized locations increase population coverage to 15% and geographic coverage to 21% with two fire stations; in three fire stations, including a newly added fire station, the population coverage increases by 48% increment, and the geographic coverage increases to 71%, which covers 88% of the total city population (Oh, J. Y., Hessami, A., & Yang, H. J., 2019).

The site selection and layout planning of fire stations in cities is a crucial content of fire safety, and it provides essential support for emergency rescue and fire control. However, the fire station construction and the division of their jurisdictions in most cities of China is random, lacking scientificity and rationality. As the size of the city grows, fire hazards and loads increase continuously, which has brought significant challenges to the fire emergency response and the safe operation of the cities. This paper adopts a multi-criterion decision-making method called the Fuzzy Analytic Hierarchy Process (FAHP) and the Geographic Information System (GIS) to decide the suitable locations of fire stations in a county in China. First, it obtained a candidate set of fire station locations based on GIS; then, four main criteria of transit time, scale cost, social service, and environmental geography were decided, and each criterion was subdivided into several sub-criteria to make the site selection more specific. Afterward, these criteria and sub-criteria were compared using pairwise importance judgment matrices and multi-objective fuzzy optimization. At last, a comprehensive evaluation was conducted according to the suitability and importance of the alternative locations of the fire stations. The research results in this paper can assist policymakers in determining the most suitable locations and layout of fire stations in cities to improve the cities' overall fire control situation (Wang, W., 2019).

Guanjie et al. (2021):" Optimal fire station locations for historic wood building areas considering individual fire spread patterns and different fire risks." Many historic wood-building areas are susceptible to fire hazards. The location of fire stations shall be carefully selected to provide adequate fire protection. This study proposes an innovative procedure to determine optimal fire station locations considering the unique fire development pattern from different possible fire origins and the potential loss from daily and post-earthquake fires (PEF). The fire spread processes originating from different buildings are first simulated using a physics-based fire spread analysis; then, different optimization objectives are selected to reflect the decision makers' attitudes towards the two fire risks. A non-dominated sorting genetic algorithm (NSGA-II) is adopted to obtain the Pareto-optimal solutions, i.e., the locations of fire stations corresponding to the minimum average burnt loss for daily fire, and the minimum probability of exceeding an acceptable fire loss from PEF, respectively. The approach is applied to an ancient town in Southwest China for illustration. The proposed method can reduce the fire loss by 5% on average compared with the traditional max covering location method, and the impacts of uncertainties in the estimate of time for the fire brigade to arrive and the change of unacceptable fire loss on the optimal locations of fire stations are discussed (Hou, G., Li, Q., Song, Z., & Zhang, H., 2021).

Nyimbili et al. (2020):" GIS-based fuzzy multi-criteria approach for optimal site selection of fire stations in Istanbul, Turkey." Fire stations play a central role in protection and response activities as part of emergency management services in cases of fire incidences. With the rising urban populations and city expansions, the demand for more fire services increases. It then becomes critical to effectively plan the location of emergency facilities to adequately service the population and ensure the protection of lives and infrastructure. This study, therefore, proposes the use of the fuzzy extension of the Multi-Criteria Decision-Making (MCDM) method of Analytical Hierarchical Process (AHP), hence called fuzzy AHP, integrated with Geographic Information Systems (GIS) approach to optimally site new fire stations for the case of Istanbul region. This state-proposed fuzzy approach simulates the subjective expert judgments for the preferences of the six criteria assessed for fire station suitability mapping. It thereby accounts for the uncertainty of crisp comparison values via fuzzy triangular numbers (TFNs). The criteria weights evaluated from this procedure were used in a weighted overlay analysis of ArcGIS's reclassified criteria map layers to generate a fire station suitability map. These resultant fuzzy AHP criteria weights were validated using another MCDM technique, called Best-Worst Method (BWM), and found to be comparable and consistent. The criteria that had the most substantial influence on the selection of sites for fire stations were identified to be: the density of hazardous material facilities (DHM), a high population density (HPD), and proximity to main roads (PMR) with associated weights of 33.3%, 24.4%, and 15.2%, respectively. Based on a thorough assessment within the areas represented by class values ranging from 3 to 5 on the suitability map, a total of 34 new fire station sites were selected, complementing the existing 121 fire stations. Further, a prioritization analysis from low, medium to high was performed to plan the phases for constructing new fire stations because of competing budgetary needs and resource constraints. The methodology to achieve this was proposed and modeled for enhancing the decision-making process in urban fire station sites was selected studies (Nyimbili, P. H., & Erden, T., 2020).

Wang et al. (2021):" Spatial Optimization of Mega-City Fire Stations Based on Multi-Source Geospatial Data: A Case Study in Beijing." The spatial distribution of fire stations is an essential component of urban development and safety. For expanding mega-cities, land-use and building functions are subject to frequent changes; hence a complete picture of risk profiles is likely to be lacking. Challenges to prevention can be overwhelming for city managers and emergency responders. In this context, we use points of interest (POI) data and multi-time traffic situation (MTS) data to investigate the actual coverage of fire stations in central Beijing under different traffic situations. A method for identifying mega-city fire risks and optimizing fire station spatial distribution was proposed. First, fire risks associated with distinctive building and land-use functions and their spatial distribution were evaluated using POI data and kernel density analysis. Furthermore, based on the MTS data, a multi-scenario road network was constructed.

The "location-allocation" (L-A) model and network analysis were used to map the spatial coverage of the fire stations in the study area, optimized by combining different targets (e.g., coverage of high fire risk areas, important fire risk types). Results show that the top 10% of Beijing's fire risk areas are concentrated in "Sanlitun-Guomao," "Ditan-Nanluogu-Wangfujing," and "Shuangjing-Panjiayuan," as well as at Beijing Railway Station. Under a quarterly average traffic situation, existing fire stations within the study area exhibit good overall POI coverage (96.51%) within a five-minute response time. However, the coverage in the northwest and southwest (e.g., Shijicheng and Minzhuang) needs to be increased. On weekdays and weekends, the coverage of fire stations in the morning and evening rush hours fluctuates. Considering the factors of high-fire risk areas and major fire risk types, the optimization results show that 15 additional fire stations are needed to provide sufficient coverage. The methods and results of this research have positive significance for future urban safety planning of mega-cities (Wang, W., Xu, Z., Sun, D., & Lan, T., 2021).

3. Our Model

This research seeks to determine the optimal location of fire stations so that these stations, with a specific capacity, can respond well to the demands. Determining suitable places for establishing various urban uses depends on several factors. These factors can include minimizing the distance between the demand and the fire stations, minimizing the time to reach the demand from the fire stations, and maximizing the stations' coverage. Positioning is essential for building fire stations because quick service to places where fires have occurred is necessary to save people's lives and property; for this purpose, using methods is vital to help in this matter. The input criteria are fuzzified in this research and then entered into the genetic algorithm. This method is used to improve the location selection of fire stations. This way, the map of the studied city and the location of the current fire stations are examined. Then fuzzifying the criteria of the condition of the main streets into secondary streets, entrance incidents, the level of risk of buildings, the number of main streets into Sub, and the number of fire occurrences, are considered as input to genetic algorithm II-NSGA. Using these fuzzy criteria, this algorithm can choose the best place to build fire stations. Finally, the selected suitable places are displayed on the map. This process is shown in the flowchart below, and more explanations of each block are mentioned in the following subsection.

3.1. The Role of Fuzzification of Essential Criteria in the Proposed Method

The role of fuzzy logic in the proposed method is that the best place is announced according to the population density and access ways. The fuzzification of essential criteria is as follows:

- The condition of the primary and secondary streets
- Input events
- Risk level of buildings
- The number of primary and secondary streets
- Number of incidents of fire.

In principle, the input parameters of different decision-makers are different according to the place, time, and urban context of each geographical region that uses this idea. For example, these inputs can include the number of fires and the amount of urban traffic., the population density, the density of houses, and the density of government, military, and industrial organizations, and these parameters can determine the fire stations. It should be mentioned that the criteria that had the most substantial effect on the selection of locations for fire stations include: the density of hazardous materials facilities, high population density, and proximity to main roads; leading to the analysis of the proposed method, it is possible to use several parameters increase or decrease, which is tested during execution and the best variables are selected.

3.2. Selection of the Best Location by Genetic Algorithm II—NSGA

Selection of the best place by Genetic Algorithm II-NSGA Genetic Algorithm is a powerful method for search and optimization through the gradual improvement of the answer, which is based on the principles of natural evolution. So that the data input is fuzzy, and then with the help of genetics, the appropriate and optimal location of the fire stations is determined, and reaching high-quality answers increases the speed of convergence. NSGA-II multi-objective algorithm is used to optimize the results obtained with one or more objective functions. The steps of this algorithm are as follows (Seshadri, A., 2006).

1) Population initialization: The initial population in the NSGA-II algorithm is selected from variable dimensions. The initial population can be created randomly without prior knowledge. If there is a limitation, that limitation is also created in the initialization of the population.

2) Non-dominant sorting: evaluating the performance of entities in each iteration leads to ranking each entity according to the fitness function and crowding distances. The objective function is a function that can be used to determine the ability of an entity to survive and reproduce for the next generation. The crowding distance is used

to measure how close one of the entities is to The neighbor itself, and it is used as a set of distances of entities related to each target. It is necessary to find solutions that can achieve the appropriate values of the objective function. For this purpose, the entities are ranked according to the objective functions and the crowding distance between each entity.

3) Genetic operator: after the ranking of entities is done, those entities that had the best ranking are selected as parents, and genetic operators are used to produce children. The following objective functions are evaluated for each entity in the children's population. Genetic algorithm uses simulated binary intersection and polynomial mutation (Seshadri, A., 2006).

$$c_{1,k} = \frac{1}{2}[(1-\beta_{\mathrm{k}}), p_{1,k} + (1+\beta_{\mathrm{k}})p_{2,k}$$

$$c_{2,k} = \frac{1}{2}[(1-\beta_{\mathrm{k}}), p_{1,k} + (1+\beta_{\mathrm{k}})p_{2,k} \tag{1}$$

A) Simulated binary intersection: The values $p_{1,k}$, and $p_{2,k}$ are chosen as parents with the kth element. The i-th child and the k-th element can be obtained as follows. In this formula, the value of $\beta_{\mathrm{k}}(\geq\ 0)$ is a random number that is sampled from the density (Seshadri, A., 2006).

$$\mathrm{p}(\beta) = \frac{1}{2}(\eta_c+1)\beta^{\eta_c}, if\ 0 \leq \beta\ \leq\ 1$$

$$\mathrm{p}(\beta) = \frac{1}{2}(\eta_c+1)\frac{1}{\beta^{\eta_c+2}}, if\ \beta\ >\ 1 \tag{2}$$

This distribution can be obtained using a random number whose value is uniformly sampled as (0, 1) (Seshadri, A., 2006).

$$\beta(u) =\ (2u)^{\frac{1}{\eta_{\mathrm{m}}+1}}$$

$$\beta(u) = \frac{1}{[2(1-u)]^{\frac{1}{\eta_{\mathrm{m}}+1}}} \tag{3}$$

B) Polynomial mutation :It considers the value of p_k As the parent, which is in the range)p_k^l ،p_k^u،(. The child c_k is generated as follows (Seshadri, A., 2006).

$$c_k = p_k(p_k^u - p_k^l)\delta_k \tag{4}$$

In the given formula, the value of δ_k is a small variable whose value can be obtained using a polynomial distribution (Seshadri, A., 2006).

$$\delta_k = (2r_k)\frac{1}{\eta_{\mathrm{m}}+1} - 1, if\ r_k < 0.5$$

$$\delta_k = 1 - [2(1-r_k\ )]^{\frac{1}{\eta_{\mathrm{m}}+1}}, r_k \geq 0.5 \tag{5}$$

In this formula, the value of η_{m} is an index of mutation distribution, and the value of r_k is a uniform random sample number representing a number between (0, 1). Recombination and selection: In this part, parents and children are combined, and non-dominant sorting is done by evaluating the fitness function. Then, the best entities are selected as the parents of the next generations. Non-dominant entities are those entities that do not have any superiority over other entities. The rank (proportion) of the entities is such that those entities in the first part are a non-dominant set. However, the

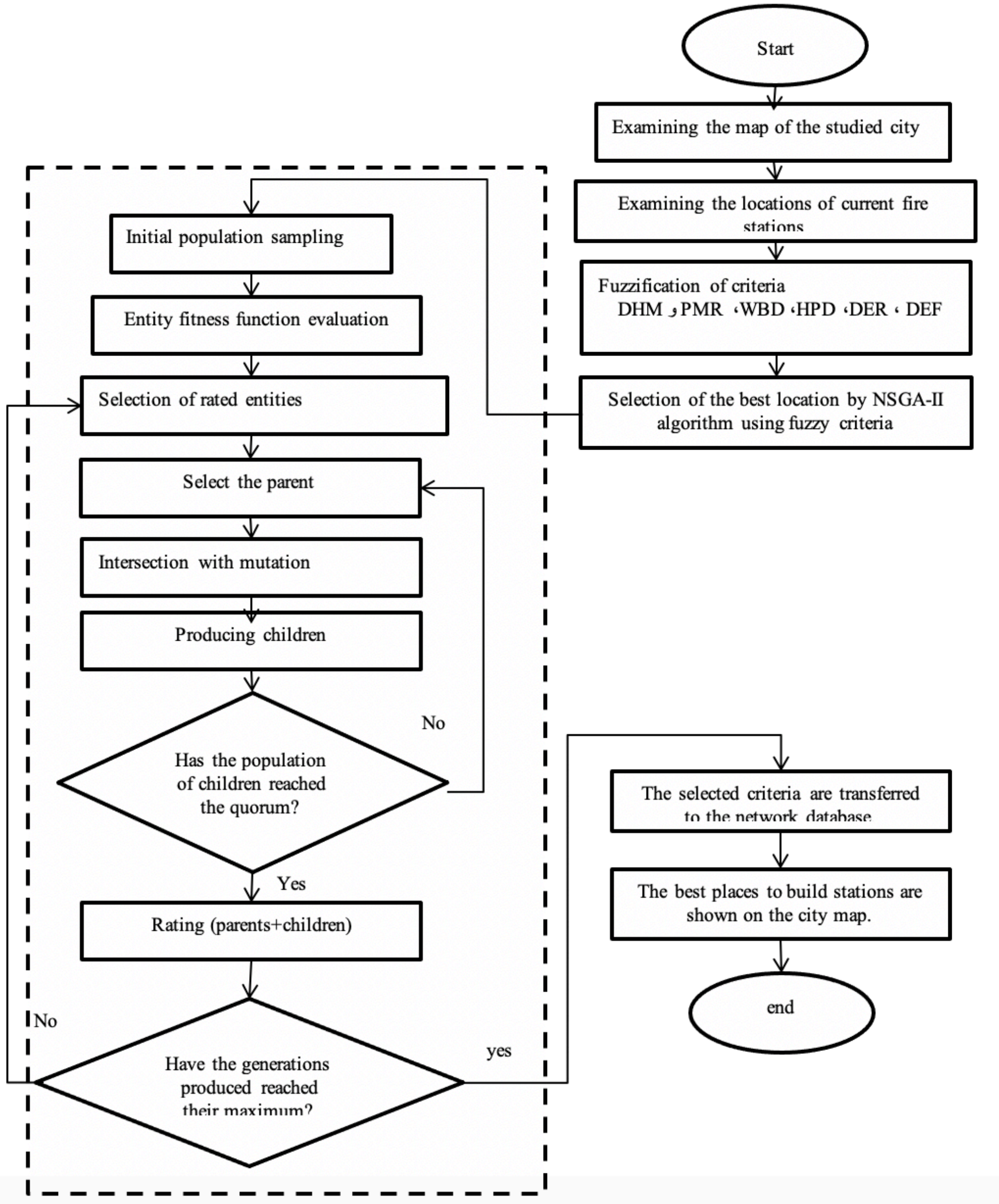

Fig.1: Flowchart of the proposed method

entities of the second Pareto are influenced by the chromosomes in the first Pareto.

The entities in the first part have priority and are selected according to their priority. However, if their population does not reach the desired size, the entities are selected from the second Pareto. This work continues until the number of entities is sufficient to start the next iteration (Seshadri, A., 2006).

4. Simulation Results and Analysis

The word crisis means the occurrence of unexpected events. These events can be manufactured or occur naturally, and if they happen, they disrupt the routine of daily life. For this reason, it is necessary to manage these crises, and if they are done correctly, they can reduce their effects to some extent. The optimum location of stations related to relief and emergency services, such as police stations, ambulance, and fire departments., is considered one of the most necessary measures to control the crisis. The deployment and waiting of fire engines and their optimal location, related to people's lives and property, can show their importance in the crises that have occurred. First, the input criteria are fuzzified to improve the location of fire stations. Then these fuzzified values are entered as input to the NSGA-II multi-objective algorithm to find the best place for station deployment. Firefighters specified. This process has been implemented with the help of MATLAB simulation software, and the related results are presented and analyzed in the form of graphs in the rest of the chapter. The fire stations that exist in the city as a part of emergency management services play an essential role in controlling such situations. The occurrence of such incidents has also increased with the expansion of the population in cities.

For this purpose, the places chosen to build fire stations should be done with care and planning to provide faster relief to the citizens. Using the fuzzification method can be very helpful in achieving this goal. This approach leads to a proper mapping based on those criteria by examining the relevant criteria. Fuzzification is done using fuzzy triangular numbers. The introduced criteria are validated using the best-worst technique. Locating fire stations is one of the necessities because it makes the fire engines go to the scene of the accident faster and prevent more damage to people's lives and property. For this reason, it is necessary to use methods to achieve this goal.

First, you should be able to find the location of the fire stations on the map. The input criteria must be fuzzified and entered into the genetic algorithm to achieve this goal. The map studied in this study is the city of Istanbul.

To find the locations of the stations, the criteria of Distance From The Existing Fire Station (DEF), Distance From Areas Exposed To Earthquake Risk (DER), High Population Density (HPD), Wooden Building Density (WBD), Proximity To The Main Roads (PMR) and Density Of Hazardous Material Facilities (DHM) be fuzzified. To be Then, this algorithm, using fuzzy criteria, presents the most suitable place on the map for establishing the stations.

4.1. Datasets

The data set used in this research is the data related to the location of the current fire stations, which includes the station's name, the station's location, and their coordinates, and it has 124 data. Also, this data set includes the data of the areas where the fire occurred and includes the name of the fire department, the location of the fire, and the coordinates of that area, and it has 107 data. An example of this data is given in Tables 1 and 2.

Table 1: Sample data related to the location of fire stations.

Row	Coordinates	Name of the region	Station name
1	40.87172994,29.13762931	ADALAR	Adalar İtfaiye İstasyonu
2	41.27821768,28.80994231	EYÜPSULTAN	Akpınar Mahallesi Gönüllü İtfaiye İstasyonu
3	41.091980, 28.917401	GAZİOSMANPAŞA	Akşemsettin İtfaiye İsta-syonu
4	41.18315865,29.45650909	ŞİLE	Alacalı Mahallesi Gönüllü İtfaiye İstasyonu
5	41.079838, 28.937221	EYÜPSULTAN	Alibeyköy İtfaiye İsta-syonu

Table 2: Sample data related to the areas where fires occurred.

Row	Coordinates	fireplace	The name of the fire department
1	41.04882, 28.050901	İtfaiye Binalari-Silivri Gümüşya-ka Müfrezesi	İtfaiye Gümüşyaka Müfrezesi
2	40.885917, 29.352973	İtfaiye Binalari-Tuzla Orhanli Müfrezesi	Orhanli Müfrezesi
3	41.016583, 28.954052	İtfaiye Binalari-Fatih Acil Yardim Ve Can Kurtarma Müd.	Acil Yardım Ve Can-kurtama Müdürlüğü Silivrikapı
4	40.871698, 29.137574	İtfaiye Binalari-Adalar Grup Amirliği	Ada Grup Amirliği
5	41.137233, 29.856169	İtfaiye Binalari-Şile Ağva Mü-frezesi	Ağva Müfrezesi

4.1. Definition of the objective function

In this research, the NSGA-II algorithm is used because it can be used to calculate one or more objective functions. A city is valued as a block using criteria such as DEF, DER, HPD, WBD, PMR, and DHM. Fire station points are also used as input to the NSGA-II algorithm. This algorithm has an objective function with two characteristics. One is to optimize urban coverage, and the other is to optimize the number of fire stations. On the one hand, the goal is to deploy these stations in a way that provides maximum urban coverage. However, on the other hand, according to the cost of setting up each station, it seeks to reduce the number of stations.

Table 3: Description of the criteria used.

Variable	Title
DEF	Distance From The Existing Fire Station
DER	Distance From Areas Exposed To Earthquake Risk
HPD	High Population Density
WBD	Wooden Building Density
PMR	Proximity To The Main Roads
DHM	Density Of Hazardous Material Facilities

4.2. Results

According to the map of Istanbul, the potential areas for establishing fire stations have been identified in this section. The results of this simulation were done by MATLAB software, and the results are given below. These experiments have been carried out using web services related to aerial maps, urban information, and information on the location of existing fire stations.

Table 4: Registered places

Type	lon	lat	ID
Residential building	28.6592628	41.3053954	355125429
agricultural land	28.6589924	41.2900911	622639608
fire station	28.7320590	41.2751618	6455269163
bus station	28.6119673	41.3106687	7096059986
Residential building	28.6609780	41.3055551	355125752
Residential building	28.6176436	41.3363591	3708244927
Residential building	28.6042943	41.2912032	2612366558

Table 5: Registered streets.

Y	x	ID
28.6631178	41.2702507	31518949
28.6711344	41.2739585	31518979
28.6771340	41.3395374	31519183
28.6609690	41.3052694	31735608
28.6681501	41.2939773	51575310
28.6118160	41.3098526	137097719
28.6525111	41.2741805	172425326

The input of the genetic algorithm is defined as follows. The genetic algorithm is allowed to select 100 new stations. It uses zero indicators if it wants to use something other than fireman opportunity. In this case, the number of new stations is added to the number of non-zero genes.

Table 6: Genetic algorithm input.

Chro- mosome number	Place 100	…	Place 3	Place 2	Place 1
1	41.291028 28.650288	…	0	41.273911 28.529363	41.305372 28.659382
2	41336238 28.669372	…	41.336292 28.671223	41.281384 28.532921	41.312822 28.661821
3	0	…	41.3307314 28.708821	0	41.2554664 28.6506814
4	41.293277 28.663282	…	41.324388 28.689378	41.271293 28.652389	41.339764 28.684262

Table 7: output results of the objective function.

Chro- mo- some	Objective two: decrease the percentage of the number of stations (percentage)	The goal is to reduce the per- centage of urban non-coverage (percentage)
1	0.12	5.39
2	0.36	2.38
3	0.23	1.38
4	0.21	1.98

For each of the chromosomes, the objective function is investigated. The following results are the output of the target function of this research. As seen, the results of the target function can be effective in the evolution of the genetic algorithm. The genetic algorithm has finally provided the optimal solution by repeating its operators 100 times. The city is divided into 1000 x 1000 blocks and is valued according to the scenarios' criteria. In this case, the genetic algorithm can make a more optimal and correct choice based on the values of these blocks. Then the genetic algorithm for station optimization is discussed. In the following, 5 scenarios were considered to find the optimal location of the stations. In this scenario, the points of the city entered the computing space. The following data is an example of input data. These data include registered locations and the center of urban streets.

Table 8: Examining the variables in five scenarios.

Variable	Scenario 5	Scenar- io 4	Scenario 3	Scenar- io 2	Scenario 1
DEF	☑	☑	☑	☑	☑
DER	☑	☑	☑	☑	☑

HPD	✓	✓	✓	✓	
WBD	✓	✓	✓		
PMR	✓	✓			
DHM	✓				

In Figure 2, the results of this scenario are displayed, and each result is explained based on the considered parameters.

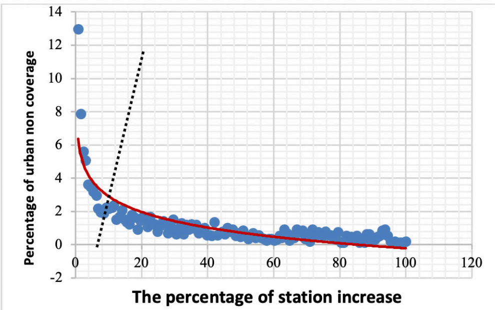

Diagram A: The effect of two parameters, Distance From The Existing Fire Station and Distance From Areas Exposed To Earthquake Risk

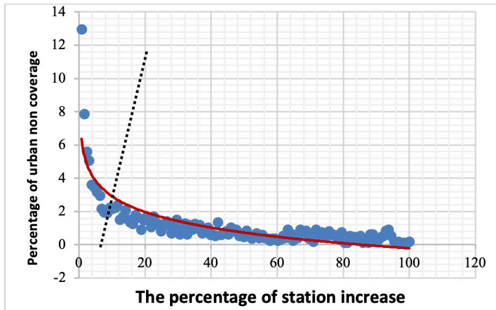

Diagram B: The effect of Three parameters Distance From The Existing Fire Station, Distance From Areas Exposed To Earthquake Risk, and High Population Density

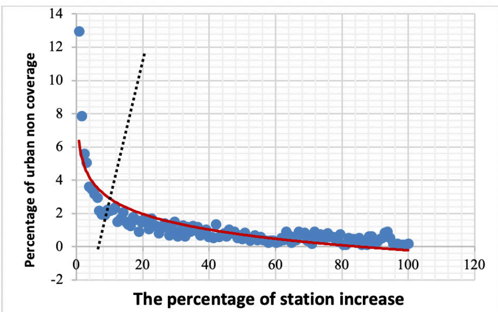

Diagram C: The effect of Three parameters Distance From The Existing Fire Station, Distance From Areas Exposed To Earthquake Risk, High Population Density, and Wooden Building Density

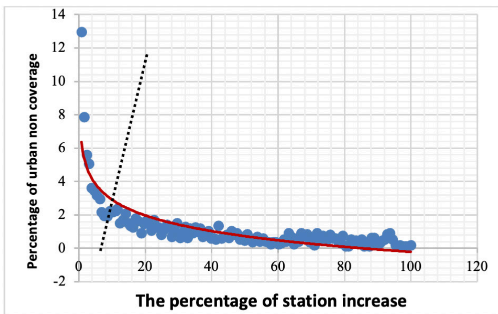

Diagram D: The effect of Three parameters Distance From The Existing Fire Station, Distance From Areas Exposed To Earthquake Risk, High Population Density, Wooden Building Density, and Proximity To The Main Roads

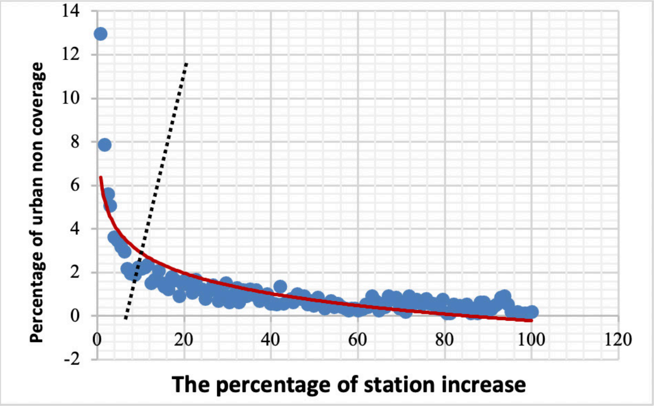

Diagram E: The effect of Three parameters Distance From The Existing Fire Station, Distance From Areas Exposed To Earthquake Risk, High Population Density, Wooden Building Density, Proximity To The Main Roads, and Density Of Hazardous Material Facilities

Fig.2: The results of different scenarios of influencing the distance parameter from the existing fire station based on variable parameters

Scenario one (Figure A): In this scenario, two parameters, the distance from the existing fire station and the distance from the areas at risk of earthquakes, have been selected to influence the selection of the parent in the genetic algorithm. If both goals have the same weight, the best answer occurs when the number of stations is 3.82. In fact, by increasing the number of stations by 5, the urban coverage reaches 96.18.

Scenario two (Diagram B): In this scenario, three parameters, the distance from the existing fire station, the distance from the areas at risk of earthquakes, and the high population density, have been selected to influence the selection of parents in the genetic algorithm. The best answer occurs if both targets have the same weight in the case where the number of stations is 4.21. In fact, by increasing the number of stations by 6, the urban coverage reaches 95.79.

Scenario three (Diagram C): In this scenario, four parameters, distance from the existing fire station, distance from areas at risk of earthquakes, high population density, and density of wooden buildings, have been selected to influence the selection of the parent in the genetic algorithm. If both goals have the same weight, the best answer occurs when the number of stations is 3.23. In fact, by increasing the number of stations by 4, the urban coverage reaches 96.77.

The fourth scenario (Diagram D): In this scenario, four parameters are the distance from the existing fire station, the distance from the areas at risk of earthquakes, high population density, the density of wooden buildings, and the proximity to the main roads to influence the selection of the parent in the algorithm. Genetics is selected.

If both goals have the same weight, the best answer occurs when the number of stations is 2.84. In fact, by increasing the number of stations by 4, the urban coverage reaches 97.16.

The fifth scenario (Diagram E): In this scenario, four parameters are the distance from the existing fire station, the distance from the areas at risk of earthquakes, the high population density, the density of wooden buildings, the proximity to the main roads and the density of hazardous materials facilities to influence on The selection of the parent is selected in the genetic algorithm. If both goals have the same weight, the best answer occurs when the number of stations is 2.42. In fact, by increasing the number of stations by 3, the urban coverage reaches 97.58.

1- Conclusion and future work

When an accident or crisis occurs, the placement of fire stations is necessary for timely and quick relief. Because the delay in responding and providing aid can cause irreparable damage to the lives and property of citizens, for this purpose, locating fire stations can prevent such incidents from happening. The NSGA-II algorithm and fuzzification method have been used to improve the location of fire stations. The criteria that are needed for locating the stations have been reviewed. The criteria used in this research are DEF, DER, HPD, WBD, PMR, and DHM. In this algorithm, first, the initial population sampling is done, then the fitness function of the entity is evaluated. Then, the ranked entities are selected.

In the following, the parents are selected, crossovers and mutations are obtained, and the children are produced. At this stage, the question has been raised whether the population of children has reached the quorum. If the condition is met, the ranking of the parents and the children have been done; otherwise, it returns to the parents' selection stage. Finally, another question has been raised whether the new generations produced have reached their maximum. If they have, the selected criteria have been transferred to the network database, and finally, The best place to build new stations is shown. Otherwise, it returns to the stage of selecting ranked entities, and these steps are repeated. In this research, the dataset of fire stations in Istanbul city has been used. This data set contains two parts, one of which contains information about the location of the stations and has 124 data. The other contains information about the areas where the fire occurred and has 107 data. This research has two objective functions, one of which is to optimize urban coverage, and the other is to optimize the number of fire stations. The goal is to deploy the stations in such a way as to provide maximum urban coverage.

However, on the other hand, according to the cost of setting up each station, it seeks to reduce the number of stations. The results obtained in this research were obtained using MATLAB software, and the results are as follows. The first scenario uses two parameters, and their influence on the parent's choice has been investigated. The results of this scenario are shown in diagrams 2-4. The best answer is obtained if both goals have the same weight and occur when the number of stations has reached

3.82. In fact, with the increase in the number of stations to 5, the urban coverage has reached 96.18. The second scenario uses three parameters, and their influence on the parent's choice has been investigated. The results of this scenario are shown in diagrams 3-4. The best answer is obtained if both goals have the same weight, and it occurs in the case that the number of stations has reached 4.21%. In fact, by increasing the number of stations to 6, the urban coverage has reached 95.79. The third scenario uses four parameters, and their influence on the parent's choice has been investigated. The results of this scenario are shown in diagrams 4-4. The best answer is obtained if both goals have the same weight and occur when the number of stations has reached 3.23%. In fact, with the increase in the number of stations to 4, the urban coverage has reached 96.77. In the fourth scenario, four parameters are used, and their influence on the parent's choice has been investigated. The results of this scenario are shown in diagrams 5-4. The best answer is obtained if both goals have the same weight, and it occurs when the number of stations has reached 2.84%. In fact, with the increase in the number of stations to 4, the urban coverage has reached 97.16. In the fifth scenario, four parameters are used, and their influence on the parent's choice has been investigated. The results of this scenario are shown in Figure 6-4. The best answer is obtained if both goals have the same weight and occur when the number of stations has reached 2.42%. In fact, by increasing the number of stations to 3, the urban coverage has reached 97.58.

The suggestions in line with the subject can be as follows:

• Improving the positioning of firefighting forces based on fuzzy logic and particle swarm algorithm.

• They are improving the positioning of firefighting forces by selecting features by the ant colony algorithm.

Reference

Dey, A., Heger, A., & England, D. (2021). Urban Fire Station Location Planning: A Systematic Approach using Predicted Demand and Service Quality Index. arXiv preprint arXiv:2109.02160

Han, B., Hu, M., Zheng, J., & Tang, T. (2021). Site selection of fire stations in large cities based on actual spatiotemporal demands: A case study of nanjing city. *ISPRS International Journal of Geo-Information, 10*(8), 542.

Hou, G., Li, Q., Song, Z., & Zhang, H. (2021). Optimal fire station locations for historic wood building areas considering individual fire spread patterns and different fire risks. *Case Studies in Thermal Engineering, 28,* 101548.

Khanahmadi, M., Arabi, M., Vafaienejad, A., & Rezaiean, H. (2014). Locate fire stations Using Fuzzy Logic and AHP integration in GIS environment (Case Study: District 1 District 10 of Tehran). *Scientific-Research Quarterly of Geographical Data (SEPEHR), 23*(89), 88-98.

Nyimbili, P. H., & Erden, T. (2020). GIS-based fuzzy multi-criteria approach for optimal site selection of fire stations in Istanbul, Turkey. Socio-Economic Planning Sciences, 71, 100860.

Oh, J. Y., Hessami, A., & Yang, H. J. (2019). Minimizing response time with optimal fire station allocation. *Stud Eng Technol, 6*(1), 47-58.

Seshadri, A. (2006). A fast elitist multiobjective genetic algorithm: NSGA-II. MATLAB Central, 182.

Suzuki, T., & Satoh, E. (2020). An analysis on the optimum location of fire department based on ambulance dispatch situation—A case study in Utsunomiya City. *Japan Architectural Review, 3*(2), 241-255.

Wang, W. (2019). Site Selection of Fire Stations in Cities Based on Geographic Information System and Fuzzy Analytic Hierarchy Process. Ingénierie des Systèmes d'Information, 24(6).

Wang, W., Xu, Z., Sun, D., & Lan, T. (2021). Spatial optimization of mega-city fire stations based on multi-source geospatial data: A case study in Beijing. *ISPRS International Journal of Geo-Information, 10*(5), 282.

Yao, J., Zhang, X., & Murray, A. T. (2019). Location optimization of urban fire stations: Access and service coverage. Computers, *Environment and Urban Systems, 73,* 184-190.

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