Efficient Firefighting in İzmir

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***Abstract*—This project focuses on optimizing the allocation of firefighting resources in İzmir, Turkey, to reduce response time and enhance effectiveness during fire emergencies. The study employs metaheuristic algorithms including Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Simulated Annealing (SA) to devise strategic distribution plans for firefighting resources. Factors such as incident location, severity, resource availability, and logistical constraints are considered in the optimization process. The results demonstrate significant improvements in response time and resource efficiency, highlighting the potential of metaheuristic algorithms in addressing complex resource allocation problems.**

I. Introduction

The increasing frequency of fire emergencies in urban areas necessitates the efficient allocation of firefighting resources to minimize damage and save lives. İzmir, Turkey, faces similar challenges due to its population density, urban sprawl, and diverse geographical features. Traditional resource allocation methods may not effectively address the dynamic nature of fire emergencies, leading to prolonged response times and suboptimal resource utilization. This project aims to develop a strategic distribution plan for firefighting resources in İzmir using metaheuristic algorithms, which offer robust solutions to complex optimization problems.

II. Problem Description

Despite preventive measures, fires continue to pose a significant threat to İzmir's safety. The efficient deployment of firefighting resources is crucial to minimize damage and save lives. Factors such as incident location, severity, resource availability, and logistical limitations influence the effectiveness of firefighting operations. Traditional resource allocation methods may not adequately address these factors, necessitating the use of advanced optimization techniques.

III. Method Formulation

To achieve the objective of optimizing firefighting resource allocation in İzmir, three optimization techniques are proposed: Genetic Algorithms, Particle Swarm Optimization, and Simulated Annealing. These methods are selected due to their ability to handle complex optimization problems and their effectiveness in finding near-optimal solutions in a reasonable timeframe.

A. Problem Definiton

In the problem, there are 29 districts which are denoted as d_i (for i= 1,...,29) and each of them has the parameters:
f_i: The number of fire incidents in district d_i
s_i: The number of fire stations currently allocated to district d_i
a_i: The average arrival time of fire stations to district d_i
k_i: The constant which is calculated as $a_i \times s_i$

Constraints of the Problem:
The total number of fire stations $\sum_{i=1}^{N} s_i$ should not exceed the maximum allowable stations, which is the sum of the current total number of stations and an additional budget which is determined as 5 in this problem:

$$totalStations + budget = maxStations \tag{1}$$

Objective Function for SA Algorithm:

$$\sum_{i=1}^{N} \frac{k_i}{s_i} \times f_i = T \tag{2}$$

where T represents total average time.
In SA algorithm, the objective is to minimize the total weighted response time T across all districts of İzmir.
Objective Function for GA and PSO Algorithms:

$$\frac{\sum_{i=1}^{N} \frac{k_i}{s_i} \times f_i}{\sum_{i=1}^{N} f_i} = F(s) \tag{3}$$

where $F(s)$ represents weighted average response time and s represents the vector of allocation of fire stations.
In GA and PSO algorithms, the objective is to minimize the weighted average response time across all districts of İzmir.

B. Genetic Algorithms (GA)

This method encodes firefighting resource allocation as chromosomes, with genes indicating resource distribution across İzmir. Genetic operators like mutation and crossover are used to explore solutions, considering response time, resource efficiency, and fire severity.

C. Particle Swarm Optimization (PSO)

This method models resource allocation plans as particles in a swarm, updating them based on individual and collective performance. The goal is to minimize response time and maximize resource effectiveness, considering factors like proximity to incidents, fire severity, and available resources.

D. Simulated Annealing (SA)

This random search algorithm accepts or rejects solutions based on a temperature parameter. The temperature decreases over time to converge towards an optimal solution, taking into account İzmir's firefighting constraints such as limited equipment and varying terrain.

IV. Real-World Application

In this project, the aim is to optimize resource allocations for firefighting in İzmir, Turkey, with the objective of minimizing the negative effects of fires. Utilizing real data from İzmir (Fig. 1, Fig. 2), it was observed that the total number of firefighter groups in İzmir is 92. Considering the possibility of adding up to 5 additional firefighter groups, the optimized distribution of firefighter groups across each district was determined using SA, GA, and PSO algorithms separately. The goal of this optimization process was to minimize the total response time to fires, thus mitigating the adverse impacts of fire incidents.

A. Datasets

Real data from İzmir was utilized in the project, sourced from the National Smart City Open Data Platform. The first dataset(Fig. 1)[1] comprises the geographical locations and lists of firefighting groups in İzmir, while the second dataset(Fig. 2) [2] contains firefighting intervention statistics for İzmir in the year 2023.

	ILCE	KAPINO	ENLEM	ACIKLAMA	ILCEID	MAHALLE	MAHALLEID	ADI	BOYLAM	YOL
0	BUCA	50A	38.405638		8	AYDOĞDU	None	Afet Koordinasyon Merkezi	27.191664	ŞEHİT ER MEHMET ÇADIRCI
1	BERGAMA		39.253723	+90(232) 293 89 12	999	YUKARIBEY	None	Bergama Yukarıbey İtfaiye İstasyonu	27.090147	KOCA
2	TORBALI	2	38.130210		9	ÇAYBAŞI	None	Çaybaşı İtfaiye İstasyonu	27.385091	7135
3	ÇİĞLİ	817	38.487233		16	ATAŞEHİR	None	Çiğli İtfaiye İstasyonu	27.074607	ANADOLU
4	DİKİLİ	10	39.077939		995	İSMETPAŞA	None	Dikili İtfaiye İstasyonu	26.896778	SANAYİ

Fig. 1. Geographical Locations and Lists of Firefighting Groups in İzmir

	ILCE	YANGIN_SONUCU	VARIS_SURESI (DAK.)	KULLANILAN_KOPUK_MIKTARI (KG)	KULLANILAN_SU_MIKTARI (m3)	KULLANILAN_KURU_KIMYEVI_TOZ_MIKTARI (KG)
0	KARABAĞLAR	BAŞLANGIÇTA SÖNDÜRÜLEN	4.0	0.0	1.0	0.0
1	KONAK	BAŞLANGIÇTA SÖNDÜRÜLEN	3.0	0.0	0.5	0.0
2	KONAK	BAŞLANGIÇTA SÖNDÜRÜLEN	2.0	0.0	0.0	0.0
3	BORNOVA	KISMEN YANARAK KURTARILAN	4.0	0.0	2.0	0.0
4	URLA	BAŞLANGIÇTA SÖNDÜRÜLEN	6.0	0.0	0.4	0.0

Fig. 2. Firefighting Intervention Statistics for İzmir

The two datasets are used to determine, for each district, the number of firefighter groups, the occurrences of fires in 2023, and the average arrival time to the incident location. Subsequently, a new dataset is created and utilized in the project (Fig. 3).

	ILCE	ITFAIYE_GRUP_SAYISI	YANGİN_SAYİSİ	ORTALAMA_VARIS_SURELERI
0	ALİAĞA	2	411	6.305623
1	BALÇOVA	2	142	3.880282
2	BAYINDIR	1	291	9.807560
3	BAYRAKLI	4	434	4.497696
4	BERGAMA	2	612	7.044118
5	BEYDAĞ	1	44	10.340909

Fig. 3. Fire Incident Data per District in İzmir

V. Experimental Evaluation

The optimization problem in this project involves determining the optimal number of firefighter groups for each district in İzmir, which currently stands at 92, with the potential addition of up to 5 more groups as decided for this project. In addition to minimizing the total response time for all districts, the average response time of all districts is calculated to be 8.44. Districts with a response time higher than the average are identified, as illustrated in Fig. 4. Furthermore, it can be observed that the application of the algorithms results in an increase in the number of firefighter groups in these districts across most algorithms.

	ILCE	ORTALAMA_VARIS_SURELERI
2	BAYINDIR	9.807560
5	BEYDAĞ	10.340909
13	KARABURUN	9.805556
18	KİRAZ	13.106383

Fig. 4. Districts with Above-Average Response Times Dataset

The problem is solved using three different algorithms.

A. Simulated Annealing

-The objective function calculates the total response time based on the allocation of firefighter groups.
-The algorithm iteratively adjusts the number of stations in each district, accepting or rejecting changes based on a probability that decreases over time.
-The best allocation of firefighter groups is found, minimizing the total response time.

B. Genetic Algorithm

-The fitness function calculates the weighted average response time for a given allocation of firefighter groups.
-An initial population of possible solutions is created, and selection, crossover, and mutation operations are performed over multiple generations to evolve better solutions. -The best individual (allocation) is selected based on its fitness, representing the optimal allocation of firefighter groups.

C. Particle Swarm Optimization

-The fitness function is the same as in the genetic algorithm.
-Particles represent possible allocations of firefighter groups, and their velocities are adjusted based on personal and global

best positions.
-The algorithm iteratively updates particles to converge towards the optimal allocation.

The comparison of the number of firefighter groups before and after application of the algorithms can be seen in Table 1 and Fig. 5.

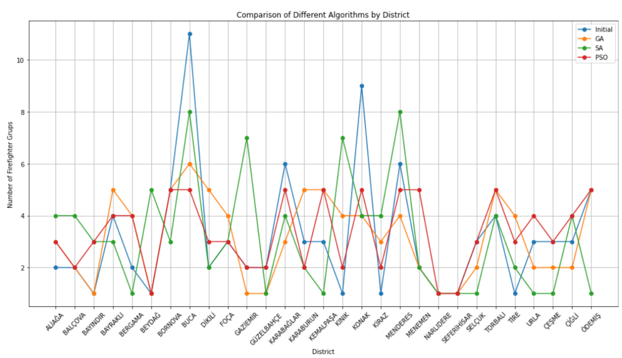

Fig. 5. Comparison of the Number of Firefighter Groups Before and After Application of the SA, GA and PSO Algorithms

TABLE I
COMPARISON OF THE NUMBER OF FIREFIGHTER GROUPS BEFORE AND AFTER APPLICATION OF THE SA, GA AND PSO ALGORITHMS

District	Current	SA	GA	PSO
Aliağa	2	4	5	3
Balçova	2	4	2	2
Bayındır	1	1	5	3
Bayraklı	4	1	4	4
Bergama	2	4	2	4
Beydağ	1	2	2	1
Bornova	5	3	5	5
Buca	11	8	6	5
Dikili	2	2	4	3
Foça	3	1	2	3
Gaziemir	2	1	5	2
Güzelbahçe	2	3	2	2
Karabağlar	6	2	3	5
Karaburun	3	1	2	2
Kemalpaşa	3	1	2	5
Kınık	1	4	1	2
Konak	9	2	3	5
Kiraz	1	2	4	2
Menderes	6	1	3	5
Menemen	2	1	5	5
Narlıdere	1	1	2	1
Seferihisar	1	4	2	1
Selçuk	3	1	1	3
Torbalı	4	2	6	5
Tire	1	4	2	3
Urla	3	9	4	4
Çeşme	3	2	5	3
Çiğli	3	12	4	4
Ödemiş	5	9	4	5

VI. CONCLUSION

The optimization techniques applied to the problem of firefighting resource allocation in İzmir demonstrate the potential to significantly improve response times and resource efficiency. Each method—Simulated Annealing, Genetic Algorithms, and Particle Swarm Optimization—provides a robust framework for tackling the complex problem of resource distribution. By implementing these methods, İzmir can develop a strategic plan that minimizes fire response times, maximizes resource effectiveness, and ultimately enhances the safety and well-being of its residents. The results show that with careful planning and optimization, it is possible to allocate firefighting resources more effectively, leading to quicker response times and better management of fire emergencies.

REFERENCES

[1] https://openapi.İzmir.bel.tr/api/ibb/cbs/itfaiyegruplari
[2] https://acikveri.bizİzmir.com/dataset/95bec47b-a29c-4ab0-a070-434334588da8/resource/f718e29e-0e3f-4b63-8019-e1920ca94330/download/2023-yili-yangin-mudahale-istatistigi.xlsx