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RESEARCH ARTICLE

AN INTEGRATED MODEL PROPOSAL FOR INCREASING THE EFFECTIVENESS OF SECURITY SERVICE PRODUCTION: A MULTI-CRITERIA MAXIMAL COVERING MODEL

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ABSTRACT

The loss of life and property can be prevented by the timely and efficient intervention of the intervention units to social events (IUSE). In this study, in order to increase the effectiveness of IUES, it's aimed to provide decision support for them to be used most efficiently re-deployment to the district stations. In this context, criticality values obtained by the event (incident) points to be covered by the IUSE in order to benefits, opportunities, costs and risks criteria, for Erzurum province experience and it's provided input to the mathematical model with obtained criticality values. Optimal solutions, obtained from proposed multi-criteria maximal covering model, is presented to decision makers. A 22% improvement is achieved at covering rate of the event points with changing the deployments of three units. It is obtained that for reaching 100% coverage, it will be needed to establish four new units more. The obtained results have been evaluated by the experts and found reasonable.

INTRODUCTION

Across the country, security and safety services are provided through public and private law enforcement forces (LEF). Security services are provided by the General Directorate of Security within the boundaries of the municipality, while in rural areas policed by General Command of Gendarmerie [1]. The effectiveness of law enforcement services to be provided by the IUSE at the right place and time. The deployment problems of IUSE have the complex structure, multiple conflicting objectives and qualitative criteria so that it is difficult to handle with conventional quantitative methods. Using the proposed model in this study, decision support which is used to cover the social event points with different criticality levels for re-deployment of IUSE is formed.

In the current system, scientific principles have not been taken into consideration when locating the IUSE so that the effectiveness of the deployment decision needs to be questioned in terms of efficiency and response time.

There is no scientific decision support system to deploy the stations of IUSE to the districts across the country. Also, a general methodology or standard for the deployment of IUSE is not determined by local researches or documentations of the other countries' LEF organisations. The need of re-deploying of IUSE and re-designing the current system according to scientific principles have emerged.

In this study, a methodology has been developed within the framework of interviews with experts for the re-deployment of IUSE. In this methodology, mathematical programming and multi-criteria decision-making (MCDA) techniques are used together. Mathematical model provides maximum coverage with the minimum number of IUSE. TOPSIS method, one of the widely used MCDA technique, is used to determine the criticality value that is obtained from re-deployment of the IUSE.

A multi-criteria, maximum coverage real-world location problem is discussed in this study. The proposed methodology has been implemented to IUSE in province of Erzurum/Turkey

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and optimal solutions are presented to decision makers. In this study, in order not to violate privacy, the results are presented with the modified data.

Problem Descrıptıon

Law enforcement forces intervene the social events, which are occurring within their territorial boundaries, with IUSE. Today, serious problems exist to intervene social events and demonsrations on time. The most important reason is that the current deployment locations and the strength of the IUSE aren't determined according to threat perceptions and requirements.

Most districts that are rapidly developing today used to look like small villages not even more than twenty years ago. In those areas, rapid increase in population, along with economic, social and cultural changes have occurred over the years. These changes have increased the need for public safety and law enforcement, and the populated areas have outgrown outside of municipal borders. This caused a dramatic increase in social event density in responsibility areas, and in workload of current IUSE stations day by day. All under these conditions, for increasing the effectiveness of IUSE services, it has been the necessity of going into a new structure.

The current capabilities of IUSE are being investigated whether they are adequate or not to ensure security, safety and public order. The major considerations are number of IUSE and the coverage area of IUSE. It is desired to obtain maximum coverage with a limited number of IUSE in the responsibility area.

Currently, there are 3 different types of IUSE can be assigned in social events. Each unit differs from one another in terms of its organizational structure and staff size. Type-1 has the greatest response capability and stuff capacity. By taking into account the population in a district and the need for public safety and law enforcement, one or more of these three types of units may be located in the district stations.

In this study, a real-world problem for the re-deployment of IUSE in order to be able to intervene in timely manner and with enough force to social events are handled. Distinguishing characteristic of this type of problem, intervention effectiveness is greatly dependent on the distance between the point which social event is occured and the station which IUSE is deployed. Therefore, differences in the capabilities and capacities of the units that intervene in the social event is the most important issue to be considered. The basic idea of the civil authorities in the region is timely and adequate deployment of IUSE' forces to be able to intervene the largest number of social event that may occur. Maximum distance which IUSE can intervene effectively in the event point, is determined. Determining the location of the IUSE is discussed as a "multi-criteria maximal covering problem”.

In this paper there are two objectives. One is represented in the objective function, and the other one is modeled as a constraint. This partitioning of objectives makes the problem easier to solve. The basic objectives for this study are to: Maximize coverage in the responsibility area and limit the number of IUSE.

In this study, IUSE that can be deployed to the current 19 district stations in Erzurum, are discussed. The deployment of the different types of units in each district station will provide different levels of criticality in terms of benefits, opportunities, costs and risks criteria. Issues to be considered at this stage, benefits, costs, opportunities and risks can not have equivalent importance for the problem. For example, the deployment of IUSE is extremely important for ensuring peace and prosperity in our problem. So, costs can be relatively ignored comparing to the benefits.

Criteria are determined accourding to the expert opinion. These are; (1) suppression of social events, (2) ensuring the safety and security, (3) ensuring the state authority. covering the maximum number of event points is the purpose of the model. Covering the whole event points is not mandatory. The proposed mathematical model aims to cover the maximum event points by given covering distance. Social events can occur at any points, so the event points can be any point in the province.

In this study, event points have been determined via the current database that occurred in the last five years and 36 events points were determined in province boundaries. Social events occurred within 1 square kilometer is represented as just 1 social event point. Potentional deployment locations and social events points are presented in Fig 1.

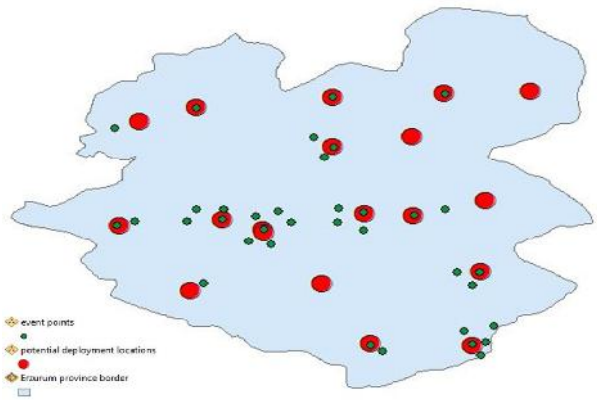

Fig 1 Potential deployment points and event points

LITERATURE REVIEW

In this study, the re-deployment problem of IUSE, is dealt with as multi-criteria maximal covering problem which is the type of facility location problems. Facility location has been a basic research area of Operation Research (OR) for years. Private sector and public institutions are both faced the facility location problems. While public institutions try to determine the location of service points (i.e., school, hospital), private sector want to determine the location of the production facilities, sale points and warehouses. Determining the location of a ciritical workplace is hard, so decision making system is vital. Numerous mathematical models have been introduced to help decision making on location decisions. Brandeauve Chiu [2] demostrate a comprehensive survey of representative problems that have been studied in location problem by identifying approximately 50 problem types and point out how those problem types relate to one another. Also, in the literature, facility location problems are classified by Daskin [3], Hamacher ve Nickel [4], Sule [5], Current *et.al*. [6], Klose ve Drexel [7], Revelle ve Eiselt [8] and Revelle *et.al*. [9].

Minimizing the total distance or time may not always be appropriate for facility location problems. Therefore, we have to find the optimal solution according to distance or time from the service points. The most important factor is determining the distance or time for acceptable service which affect the optimal solution of the covering problems [10]. There is no standards in this method so that it can be criticized. Covering problems have been discussed in two category by Schilling *et. al*. [11]. The first one is Maximal Covering Location Problems (MCLP) and the second one is Set Covering Problem (SCP). MCLP is a problem which includes certain distance or time in service to be covered by the maximum number of requests per service center that has a lot of network center [12]. MCLP was first used by the Church and Revell [12]. It was taken into account where resources are limited in the proposed model and these limitations are expressed in the constraints as the number of service centers.

The demand point has led to the emergence of a new kind of model that provides multiple covering due to the activities of non-busy or service centers in recent years. A detailed review of the covering models and solutions are made by Farahani *et.al*. [13] and Schilling *et.al* [11]. In recent years, various types of MCLP have been developed. A brief summary of them is presented in Table 1.

Table 1 A brief summary of the versions of MCLP.

Authors	The Problem Type
Aytug and Saydam [14]	Maximum Expected Coverage Location Problem -MEXCLP
Espejo *et. al*. [15]	Hierarchical MCLP
Park and Ryu [16]	Large-scale MCLP
Hogan and ReVelle [17]	Backup Coverage Location Problem-BCLP
Shavandi and Mahlooji [18]	Fuzzy queuing MCLP
Dell'Olmo *et. al*. [19]	Multi-period MCLP
Gendreau *et. al*. [20]	Double coverage problem
Başar *et. al*. [21]	Multi-period double coverage
Qu and Weng [22]	Hub-MCLP
Davari *et. al*. [23]	MCLP with fuzzy travel times
Murray *et. al*. [24]	MCLP implicit and explicit
Church [25]	Planar maximal covering
Current and Storbeck [26]	Capacitated MCLP
ReVelle and Hogan [27]	Probabilistic MCLP
O'Hanley and Church [28]	Maximum covering location-interdiction problem
Current and Schilling [29]	Maximal Covering Tour Problem-MCTP
Karasakal and Karasakal [30]	Partial coverage problem
Berman and Krass [31]	Generalized MCLP-GMCLP
Lee and Lee [32]	Generalized hierarchical covering location problem
Church and Roberts [33]	Gradual covering
Berman [34]	p-Maximal cover problem
Erdemir *et. al*.[35]	Quadratic MCLP
Naimi Sadigh *et. al*. [36]	Complementary edge covering problem-CECP
Matisziw *et. al*. [37]	Maximum Covering Route Extension Problem-MCREP
Plastria and Vanhaverbeke [38]	MCLP in competitive environments

In literature, studies about real-world location problems of safety and security forces are extremely limited. The creation of a mathematical background on this issue dates back to the 1970s. The complexity of the deployment of the problems of law enforcement and the standard will always be valid for reasons such as lack of quantitative criteria to measure effectiveness could not be determined [39]. First mathematical modeling application for the determination of patrol routes of police forces in Anaheim, California, was carried out by Mitchell [40]. In this application, the p-median problem, is adapted to the problem of determining the patrol route and total demand between responsibility areas has minimized. It is likely to occur for demand which includes the number of traffic accidents, was used in his study. Initially, it focused on patrols which can be transferred to a route that has more incidents. In this context, it is used more queuing models ([41-44]). Then, mathematical models such as; heuristics ([46]), graph theory ([50-51]) and simulation models are developed for determination of patrol routes ([45]).

Keskin *et.al*. [53] proposed a tabu search heuristic which is considering the time and budget constraints to determine the patrol routes. Murray *et. al*. [54] tackled with the placement problem of sensors to support security monitoring in 3D urban environments. They utilized visibility analysis by GIS for calculating coverage for each potential camera location. The optimal combination of cameras and their locations were modeled by MCLP and the backup coverage location problem (BCLP). Curtin *et al*. [45] studied the distribution of police patrol areas in Dallas, USA. By applying the MCLP and backup covering. They also used GIS analysis.

In literature, it was found just few studies on integrated multi-criteria covering problems. Farahani and Asgari [55] are studied on logistics support base on location problem to open the minimum number of bases for the design of a military logistics system to provide maximum service. TOPSIS, set covering, 0-1 integer and quadratic programming approaches are used in the proposed model. 33 logistics base alternative determined according to 24 criteria were evaluated by TOPSIS. Optimal base location is determined with set covering. Assignments from military bases to warehouses are determined with 0-1 integer and quadratic programming.

Data Gatherıng And Analysıs

Model inputs such as; number of social events, acceptable response distance of the units, number of units can be obtained from existing databases which it has been found for the considered deployment districts of units at data collection and analysis stage.

The number IUSE which can deployed in any district station, are also limited in nature according to organization, material and staff of law enforcement forces. Accordingly, the covering distance from the units depending on capabilities of law enforcements. There are three different types of LEF unit within law enforcement as mentioned in the problem description part. Capabilities of each type of element is different.

The IUSE carry out their public safety and law enforcement duties with the help of 24-hour patrols. When informed about an incident, arriving to the scene in at least 30 minutes is a crucial criterion for the effectiveness of the IUSE. Preparation process, arrival at the scene, and securing the area are included to that period of time. Considering the approximate speed of the vehicle is 50 km/h for Type-1 units 30 km distance is the maximum coverage distance in a 30-minute period for a Type-1 unit. For a Type-2 unit the maximum coverage distance is reduced to 20 km. And for a Type-3 unit the efficient coverage distance is 10 km. Criticality values are determined according to benefit, opportunity, cost and risk criteria by expert opinions. Quaternary rating scale including low, middle, high and very high scales which are presented in Table 2. was used to determine the priority criteria in this phase. Thus, it evaluated the effect of each strategic criteria. It has benefitted from Üstün et.al. [56]' studies to determine weight of criteria and weight of degrees including (Very High (0.513), High (0.275), Middle (0.138) ve Low (0.074)).

Table 2 1-4 evaluation scale

Benefit	Very High	High	Middle	Low
Opportunity	Very High	High	Middle	Low
Cost	Very High	High	Middle	Low
Risk	Very High	High	Middle	Low

Firstly, benefit, opportunities, costs and risks by experts for the ratings criteria are combined by taking the geometric mean. The judgment referred to the views of 12 experts in this study were combined with the formulas below.

i	=	(1: Benefit, 2: Opportunity, 3: Cost, 4: Risk),
j	=	(1: Appeasing the social event, 2: Ensuring the safety and security, 3: Establishing the State Authority),
k	=	The number of experts consulted
a_{ij}	=	Average weight of the *j*. strategic criteria of *i*. criteria for *N* expert
$_{ijk}$	=	Weight of the *i*. criteria for *j*. strategic criteria given by *k*. expert
s_j	=	Weight of the *j*. strategic criteria

$$a_{ij} = \sqrt[n]{\prod_{k=1}^{N} {}_{ijk}} \qquad \forall i, j \qquad (1)$$

After the average weights are calculated for all *i* and *j*, Eq. (2) is used to evaluate the weights (w_i) of risk, cost, opportunity and benefit. The obtained weights (Table 3.) are used in TOPSIS calculations. In this study, interviews with experts, it was decided to have equal weight in the strategic criteria.

$$w_i = \sum_{j=1}^{3} s_j a_{ij} \qquad \forall i \qquad (2)$$

Table 3 Computed criteria weights

Benefit (w_1)	Opportunity(w_2)	Cost (w_3)	Risk (w_4)
0.385	0.205	0.180	0.230

TOPSIS Calculations

In this study, criticality value which obtained in case covering each event points by IUSE was calculated by TOPSIS method. TOPSIS method was implemented using Microsoft Excel spreadsheet and formulas. For assessing the criteria, 1-10 (10 offers maximum benefit) scale was used and experts have been consulted. Consensus has been achieved in expert judgment. Subsequently, the data combined and the decision matrix of the original matrix in Table 4. has been formed. Each event point for ease of expression is shown with "D".

Table 4 Input values of the TOPSIS analysis

Weights	0.385	0.205	0.18(	0.23(	Weights	0.385	0.205	0.18(	0.230
	Benefit	Opportunity	Cost	Risk		Benefit	Opportunity	Cost	Risk
D1	6	7	7	6	D19	3	1	7	1
D2	5	4	6	3	D20	7	5	4	4
D3	4	5	8	3	D21	7	5	6	3
D4	6	8	8	7	D22	5	3	4	6
D5	4	3	5	2	D23	8	7	7	5
D6	5	4	9	3	D24	7	5	4	4
D7	4	2	8	2	D25	7	6	7	4
D8	4	2	9	1	D26	6	5	4	3
D9	5	3	7	2	D27	8	6	7	2
D10	5	2	9	1	D28	7	6	8	5
D11	3	1	8	1	D29	4	4	5	6
D12	5	3	5	2	D30	3	2	4	7
D13	3	3	4	2	D31	7	7	8	3
D14	4	2	8	1	D32	6	5	5	4
D15	4	8	7	6	D33	7	6	7	4
D16	5	2	7	3	D34	4	3	8	2
D17	6	4	6	3	D35	3	2	7	2
D18	4	3	8	2	D36	4	4	4	3

The data that has contained in the decision matrix is normalized in accordance with the TOPSIS method. Standard decision matrix is formed. Standard values obtained from the decision matrix, which multiplied by the weight value obtained from the previous step, the standard weighted decision matrix is formed. Using weighted standard decision matris, we obtained positive ideal (A^*) and negative ideal (A^-) solution sets (Table-5).

Table 5 Positive and negative ideal solutions

A^*	0,0959	0,0602	0,0437	0,0776
A^-	0,0360	0,0075	0,0194	0,0111

Criteria values must be found to deviate from the positive and negative ideal solution sets for assessment of each event point. In this context, the euclidian distance approach was used. The separation from positive ideal alternative (S_i^*) and negative ideal alternative (S_i^-) are calculated and presented in Table 6. The positive and negative separation measures of each event points have been benefitted to calculate the relative closeness to the ideal solution (C_i^*). Criterion here is the share of total separation of the ideal negative separation. The relative closeness values are presented in Table 6. And finally, criticality values are computed and ranked.

According to expert opinion the most critical event point, as shown in Table 6, is the node D27. Therefore, the covering of node D27 ensure maximum benefit. With the point of criticality, values of event points, obtained in this section, is an input to the mathematical model for the next section.

Model Formulatıon

We modelled the re-deployment problem of IUSE, taking into account the different types IUSE can be deployed in every

Table 6 Results obtained by TOPSIS

	Seperation Measures		Relative Closeness	Ranking		Seperation Measures		Relative Closeness	Ranking
	S_i^*	S_i^-	C_i^*			S_i^*	S_i^-	C_i^*	
D1	0,0718	0,0580	0,4469	**16**	D19	0,0820	0,0667	0,4487	**15**
D2	0,0713	0,0374	0,3439	**23**	D20	0,0635	0,0622	0,4947	**7**
D3	0,0772	0,0357	0,3162	**28**	D21	0,0595	0,0593	0,4993	**5**
D4	0,0740	0,0638	0,4632	**14**	D22	0,0830	0,0373	0,3102	**29**
D5	0,0728	0,0371	0,3378	**24**	D23	0,0652	0,0754	0,5361	**3**
D6	0,0739	0,0361	0,3282	**27**	D24	0,0635	0,0622	0,4943	**8**
D7	0,0795	0,0312	0,2819	**32**	D25	0,0641	0,0618	0,4911	**10**
D8	0,0702	0,0680	0,4919	**9**	D26	0,0613	0,0548	0,4721	**13**
D9	0,0676	0,0400	0,3719	**22**	D27	0,0456	0,0762	0,6256	**1**
D10	0,0626	0,0711	0,5316	**4**	D28	0,0685	0,0612	0,4716	**12**
D11	0,0827	0,0665	0,4457	**17**	D29	0,0864	0,0300	0,2576	**34**
D12	0,0655	0,0425	0,3938	**21**	D30	0,0627	0,0254	0,2021	**36**
D13	0,0807	0,0398	0,3301	**26**	D31	0,0579	0,0676	0,5386	**2**
D14	0,0694	0,0680	0,4950	**6**	D32	0,0674	0,0501	0,4263	**18**
D15	0,0826	0,0543	0,3967	**20**	D33	0,0641	0,0618	0,4907	**11**
D16	0,0797	0,0297	0,2713	**33**	D34	0,0755	0,0338	0,3092	**31**
D17	0,0661	0,0460	0,4104	**19**	D35	0,0865	0,0292	0,2525	**35**
D18	0,0755	0,0338	0,3096	**30**	D36	0,0767	0,0382	0,3326	**25**

I	=	**Set of social event points,** $i \in I$
J	=	Set of stations which the LEF units can be deployed, $j \in J$
N_i^1	=	$\{j \in J \mid d_{ij} \le 30\}, \forall i \in I$ (Set of event point at *i* covered by type-1 units)
N_i^2	=	$\{j \in J \mid d_{ij} \le 20\}, \forall i \in I$ (Set of event point at *i* covered by type-2 units)
N_i^3	=	$\{j \in J \mid d_{ij} \le 10\}, \forall i \in I$ (Set of event point at *i* covered by type-3 units)
x_j^1	=	1 If the type-1 unit is located at *j*. station, 0 otherwise.
x_j^2	=	1 If the type-2 unit is located at *j*. station, 0 otherwise.
x_j^3	=	1 If the type-3 unit is located at *j*. station, 0 otherwise.
y_i^1	=	1 If the event point *i* covered by type-1 unit, 0 otherwise.
y_i^2	=	1 If the event point *i* covered by type-2 unit, 0 otherwise.
y_i^3	=	1 If the event point *i* covered by type-3 unit, 0 otherwise.

Objective Function

$$Maks\ z = \sum_{i \in I} k_i (y_i^1 + y_i^2 + y_i^3) \qquad (3)$$

Subject to

$$y_i^1 \le \sum_{j \in N_i^1} x_j^1 \qquad \forall i \in I \qquad (4)$$

$$y_i^2 \le \sum_{j \in N_i^2} x_j^2 \qquad \forall i \in I \qquad (5)$$

$$y_i^3 \le \sum_{j \in N_i^3} x_j^3 \qquad \forall i \in I \qquad (6)$$

$$\sum_{j \in J} (x_j^1 + x_j^2 + x_j^3) \le p \qquad (7)$$

$$x_j^1 + x_j^2 + x_j^3 \le 1 \qquad \forall j \in J \qquad (8)$$

$$y_i^1 + y_i^2 + y_i^3 \le 1 \qquad \forall i \in I \qquad (9)$$

$$x_j^1, x_j^2, x_j^3 \in \{0,1\} \qquad \forall j \in J \qquad (10)$$

$$y_i^1, y_i^2, y_i^3 \in \{0,1\} \qquad \forall i \in I \qquad (11)$$

district stations within acceptable intervention distance so as to provide maximum covering. Notations and formulation of the problem is presented below.

Objective function (3) states the deployment of IUSE to ensure the maximum covering taking into account the criticality values of the event points. Constraints (4-6) are related to the coverage of event points and specifies which event points can be covered with what types of IUSE in acceptable intervention time. If a IUSE is deployed at point *j* in a covering distance to intervene the social event occured at point *i*, the event point *i* would be covered ($y_i = 1$). If not, the event point *i* wouldn't be covered ($y_i = 0$). Constraint (7) requires that exactly "*p*" number of IUSE be deployed. Constraint set (8), ensures the deployment of only one type of IUSE to any potential district station. Constraint set (9), ensures the covering of each event points by just a IUSE. Constraints (10) and (11) define the requirements for decision variables.

The model provides the optimal deployments of all three types IUSE in province of Erzurum. To verify the model, a test problem has been created to reflect the real problem. The generated test problems under different scenarios are run by changing the parameters. The test results are evaluated accurately reflect the real problem.

In order to validate the model, the results obtained from the tests problem are evaluated by the experts and found like expected.

COMPUTATIONAL RESULTS

The model encoded with GAMS and solved by CPLEX 10.1 solver. Laptop which has Intel (R) Core (TM) CPU @ 2.60GHZ i5-3320m with the operating system is used for solving the model. The longest duration of the solution of the model has been obtained for 0,017 seconds. There are 493 constraints, 166 continuous variables and 165 integer variables in the model. Three different scenarios were determined through the interviews with experts to offer several alternatives to decision makers and to provide decision support for the re-deployment problem of IUSE. Each scenario is solved by increasing the number of units (*p*) to be deployed.

Scenario Desingning And Evaluation Of The Computational Results

As a result of interviews with experts, three different scenarios were developed to examine the impacts of the unit types, acceptable intervention distance and the criticality of event points to the solutions.

We started the computational process in a way of beganning with at least one of IUSE can be deployed to district stations for each scenario. Depending on the acceptable intervention distance, number of IUSE is increased until maximum covering has been achieved. Thus, the minimum number of IUSE, may interfere to the maximum number of social events, are provided. The deployment of stations and coverage rate varies depending on the number and type of units which are deployed.

Scenario-1 Sensitivity analysis for types of IUSE

In this scenario, the combination of different types of IUSE which are deployed to district stations is provided and the model is solved. In this context, the model was solved by allowing to deploy respectively; only Type-1, only Type-2, only Type-3, Type-1 and Type-2, Type-1 and Type-3, Type-2 and Type-3, all Types together. Results of the combinations are presented in Table 7. For example, when %100 covering has been achieved and 12 units have been deployed in all Types together solution. All event points were covered in this solution.

When we assess the solution results of Scenario-1, it is seen that the maximum covering with deploying 16 units including Type-1 and Type-2. Type-1 has the maximum acceptable intervention distance, so 16 units have deployed for %100 covering. If only Type-2s are deployed, maximum covering also can be achieved.

But one event point can not be covered with it. If just Type-3s are deployed, maximum covering can be achieved with 13 units. But just 21 event points can be covered.

If two Types are been used together, all events points have been covered by 12 units including only Type-1. An event point is not covered in the third case because of the brevity of the intervention distance. The last case which used all types of unit was assessed as providing the maximum benefit. Because the number of deployed units, despite being 12, as the other two cases, try using more Type-2 and Type-3 elements and can prevent waste of resources.

Scenario-2: Sensitivity analysis for the acceptable intervention distance

We have identified that all the events points haven't been covered due to the relative brevity of the intervention distance of Types 2 and 3 units in Scenario-1.

Therefore, the effect of changes in acceptable intervention distance will be discussed. As indicated in the problem description, acceptable intervention distance of Type-1 units is 30 km., Type-2 is 20 km, and Type-3 is 10 km. These distances are determined depending on the available tools and equipment, ability of these units and number of the staff. If current units are strengthened, current intervention distance can be increased and it becomes respectively; 45, 30 and 15 km. This scenario was created to evaluate the situation which is deployment of strengthened units. The necessary changes are made in the model parameters and the model is solved again. The results are presented in Table 8.

Table 7 Results obtained by Scenario-1

Type of units	Number of deployed units	Deployed unit type and station	Obj. Func.	Covered event points	Covering rate (%)
Type-1	16	$1^1, 2^1, 3^1, 4^1, 6^1, 7^1, 8^1, 9^1, 11^1, 12^1, 14^1, 15^1, 16^1, 17^1, 18^1, 19^1$	14,619	36	100,0
Type-2	16	$1^2, 2^2, 3^2, 4^2, 6^2, 7^2, 8^2, 9^2, 11^2, 12^2, 14^2, 15^2, 16^2, 17^2, 18^2, 19^2$	14,276	35	97,2
Type-3	13	$2^3, 3^3, 4^3, 6^3, 7^3, 8^3, 11^3, 12^3, 14^3, 15^3, 17^3, 18^3, 19^3$	8,154	21	58,3
Types 1 and 2	12	$1^1, 2^1, 3^1, 4^1, 11^1, 14^1, 16^1, 18^1$ $7^2, 8^2, 12^2, 15^2$	14,619	36	100,0
Types 1 and 3	12	$1^1, 3^1, 4^1, 8^1, 11^1, 12^1, 14^1, 16^1, 18^1$ $2^3, 7^3, 15^3$	14,619	36	100,0
Types 2 and 3	14	$1^2, 6^2, 8^2, 12^2, 14^2, 16^2, 17^2, 18^2$ $2^3, 3^3, 4^3, 7^3, 11^3, 15^3$	14,276	35	97,2
All Types	12	$9^1, 11^1, 12^1, 15^1, 16^1, 18^1$ $7^2, 8^2, 14^2$ $2^3, 3^3, 4^3$	14,619	36	100,0

Table 8 Results obtained by Scenario-2

Type of units	Number of deployed units	Deployed unit type and station	Obj. Func.	Covered event points	Covering rate (%)
Type-1	8	$4^1, 6^1, 7^1, 8^1, 11^1, 12^1, 14^1, 18^1$	14,619	36	100,0
Type-2	12	$1^2, 2^2, 3^2, 4^2, 7^2, 8^2, 11^2, 12^2, 14^2, 15^2, 16^2, 18^2$	14,619	36	100,0
Type-3	14	$2^3, 3^3, 4^3, 6^3, 7^3, 8^3, 9^3, 11^3, 12^3, 14^3, 15^3, 16^3, 17^3, 18^3$	13,676	33	91,67
Types 1 and 2	8	$4^1, 6^1, 8^1, 10^1, 12^1, 14^1, 18^1$ 7^2	14,619	36	100,0
Types 1 and 3	8	$4^1, 6^1, 8^1, 10^1, 12^1, 14^1, 18^1$ 7^3	14,619	36	100,0
Types 2 and 3	12	$2^2, 3^2, 4^2, 9^2, 11^2, 12^2, 14^2, 16^2, 18^2$ $7^3, 8^3, 15^3$	14,619	36	100,0
All Types	8	$6^1, 7^1, 8^1, 10^1, 12^1, 18^1$ 15^2 4^3	14,619	36	100,0

In assessment of Scenario-2 solution results, if Type-3s are only deployed to stations, three event points can not be covered but in all other cases; maximum covering has been achieved. If %50 capacity increase at capabilities of units, the number of units to be deployed is 8. The last solution which used all types of units was assessed as providing the maximum benefit status like Scenario-1. This is why, in the last solution, although the total number of deployed units 8 likewise the other two solution, less Type-1 units and more Types 2 and 3 deployed.

In maximal covering literature, it is observed generally that authors have studied on problem in which the event points have no priorities or weights of event points are just formed with number of incident has been occured. In this context, this scenario has been created to evaluate the effectiveness of the proposed methodology. Firstly, criticality values of the event points, changed as the number of incidents.

Table 9 Results obtained by Scenario-3 and comparison to Scenario-1 results

Scenario	Type of units	Number of deployed units	Deployed unit type and station	Covered event points	Covering rate (%)
S-1	All Types	12	$9^1, 11^1, 12^1, 15^1, 16^1, 18^1$ $7^2, 8^2, 14^2$ $2^3, 3^3, 4^3$	36	100,0
S-3	All Types	12	$9^1, 11^1, 15^1, 16^1, 18^1$ $7^2, 8^2, 12^2$ $2^3, 3^3, 4^3, 14^3$	36	100,0

Table 10 Results obtained by computing the current situation

Scenario	Type of units	Number of deployed units	Deployed unit type and station	Covered event points	Covering rate (%)	Scenario
Current Status	All Types	8	$3^1, 11^1, 12^1, 14^1$ $4^2, 8^2$ $2^3, 18^3$	9,342	23	63,9

Scenario-3: Sensitivity analysis for criticality of the event points

Apart from the literature, in this study, we used criticality values of each event points accourding to the benefit, opportunity, cost and risk criteria in term of each strategic criteria for weights of affecting factors of location decisions.

Event points are prioritized in the context of the criteria for the deployment of units. In this scenario, all three elements that also deployed are used again to compare to the other scenarios (Table-9).

As a result of the Scenario-3 solution, all 36 event points are covered by 12 elements like as Scenario-1. When comparing the solution results of both scenario, although the IUSE are deployed to the same district stations in both scenario, deployed types of IUSE are been differentiated as expected.

Accourding to the both Scenarios 1 and 3 solutions, 36 event points are covered by 12 units. While, in Scenario-1, Type-1 unit is deployed to 12th station, in Scenario-3, Type-2 unit is deployed to the same station. Correlatively, In Scenario-1, Type-1 unit is deployed to 14th station, but in Scenario-3, Type-3 unit is deployed to the same station.

As forming the Scenario-3 criticality values of the event points, changed as the number of incidents; deploying lower capacity units in 12th and 14th stations due to their relative criticility, is become an optimal decision.

Assesing the event points where the occured incidents are interferred by these two stations, it is experienced that although the less incidents have been occured, the more IUSE than expected assigned in order to ensure safety.

In this regard, the proposed expert opinion based criticality assesment approach, used in this study, is considered to reflect the real world experience and concluded that it could be used as an effective decision support system by law enforcement forces.

Comparison of the computational results with current situation

Currently in Erzurum, Type-1 units are deployed in 3,11,12 and 14th stations, Type-2 units are deployed 4 and 8th stations, finally Type-3 units are deployed 2 and 18th stations. Solutions are presented in Table 10 for current situation.

Upon analyzing the current status of the solution results, 23 events are interferred by 8 LEF units. The total intervention rate within the 30-minutes was determined as 63.9%. When the negative thought, it is clear that this ratio is extremely low. Therefore, this failure should be eliminated. Making improvements are important to ensure a high level of preparation. Improvements will be achieved with the proposed model and it will be reached the desired level. Immediately it is not expected to reach the desired level so until the new deployment is accomplished. Until that day; Type-1 units can be deployed from 14th station to 18th station, Type-2 units can be deployed from 4th station to 14th station, Type-3 units can be deployed from 18th station to 4th station. If we implement these changes, the number of events that can be intervened come to 31 and coverage will also increase to 86.1 %.

Consequently, an improvement of 22% was achieved at covered the rate of the event points with changing the location of the three units. If 100% coverage is wanted, there will be needed to establish four new units more.

CONCLUSION AND RECOMMENDATIONS

In this study, a real-world location problem, the re-deployment problem of IUSE are discussed as a multi-criteria maximal covering problem for district stations which located in Erzurum province. A methodology that combines the integer programming and MCDA technique for solving the problem have been proposed. Integer programming model ensure maximum coverage of the event points with minimum number of IUSE. TOPSIS technique is used to obtain criticality values of the which one of the mathematical model inputs. The obtained results under different scenarios were evaluated. The optimal solutions to decision makers for the re-deployment of IUSE are presented. A 22% improvement is achieved at covering rate of the event points with changing the deployments of three units. It is obtained that for reaching 100% coverage, it will be needed to establish four new units more. The obtained results have been evaluated by the experts and found reasonable.

It is considered a more detailed analysis can be done using different criticality criteria as a continuation of this study. On the other hand, introducing a dynamic approach is also possible with different forecasting tools and methods which provide more realistic posibility of the social events.

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