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A Post-disaster Assessment Routing Multi-objective Problem under Uncertain Parameters

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ABSTRACT

Given that disasters are unavoidable, and many people are suffering from them each year, we should manage the emergencies and plan for them well to reduce mortality and financial losses. One of the measures that organizations must take after the disaster is the assessment of the conditions and needs of the people. We consider some characteristics for sites and roads and two teams for assessment as well as the uncertain assessment time to modeling. A multi-objective model is proposed in this study. The first objective function maximizes the gain from the assessment of areas and roads. The second and third objective functions maximize total coverage at damaged areas and roads. We use the LP-metric technique to solve small size problems in the GAMS software and the Grasshopper Optimization Algorithm (GOA) as a Meta-heuristic algorithm to solve a case study. Numerical results are presented to prove the credibility and efficiency of our model.

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NOMENCLATURE

Sets			
N	Set of all nodes (i,j ∈ N)	N_0	$N \cup \{0\}$, 0 is the origin node
A	Set of all arcs	RT	Set of Red Crescent Assessment Team (k ∈K)
GT	Set of Governmental Assessment Team (h∈H)	L	Set of all teams (l ∈ L)
C	Set of critical characteristics of nodes (c ∈ C)	R	Set of critical characteristics of arcs (r ∈ R)
S	Set of probability scenario (s ∈ S)		
Parameters			
$\widetilde{ta}_{il}^{s}$	The assessment time at node I under scenario s by team l	$\widetilde{ta}_{ijl}^{s}$	The assessment time at arc (i,j) under scenario s by team l
$Tmax_l^s$	The maximum time that team l is allowed to evaluate under scenario s	C_l^s	Transportation cost for team l per unit of distance under scenario s
$dmax_k^s$	The maximum distance that team k is allowed to traverse under scenario s	$dmax_h^s$	The maximum distance that team h is allowed to traverse under scenario s
d_{ij}	Distance from node $i \in N$ to node $j \in N$	d_{0i}	Distance from origin node to $i \in N$
Bud_{GT}^s	Total transportation budget of the Governmental team under scenario s	Bud_{RT}^s	Total transportation budget of the Red Crescent team under scenario s
α_{ic}^s	The probability that node i has the characteristic c under scenario s	α_{ijr}^s	The probability that arc (i,j) has the characteristic r under scenario s
p_i^s	The importance of node $i \in N$ under scenario s	q_{ij}^s	The importance of arc $(i,j) \in A$ under scenario s
E_{ij}	1 if arc $(i,j) \in A$ exists in the transportation network, and 0 otherwise		
Variables			
u_i	The sequence in which node i is visited	x_{0il}^s	1 if node i is first node in the path of the team l under scenario s, and 0 otherwise
x_{i0l}^s	1 if node i is last node in the path of team l under scenario s, and 0 otherwise	x_{ijl}^s	1 if team l visits node $j \in N$ after node $i \in N$ under scenario s, and 0 otherwise
A_{il}^s	1 if team l visits node $i \in N$ under scenario s, and 0 otherwise	z_{ijl}^s	1 if team l visits arc $(i,j) \in A$ under scenario s, and 0 otherwise

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1. INTRODUCTION

Human beings are threatened at any moment by natural and technological disasters. The number and magnitude of disasters have increased dramatically [1]. However, these catastrophes could not have been avoided, preparedness and response planning can eliminate or mitigate their casualties. Humanitarian supply chain has an important role in the efficient response to the affected people. One of the sections of this framework is Disaster Operations Management. It performs a set of operations before, during, and after a disaster [2]. As a matter of fact, effective response operations are impossible without disaster situation assessment and precise evaluation of demand for humanitarian and relief items. A comprehensive needs assessment should be started immediately after the disaster and completed within three days so assessment teams are not able to evaluate all demolished sites [3]. The rapid need assessments can gather a large amount of information about the post-disaster conditions. This information can be collected from different assessment teams (Red Crescent and governmental). They have to select a limited number of sites and roads. The rapid need assessments the sites can be sampled randomly or with purpose in order to be visited [4]. Purposive sampling comprises three stages of identifying critical characteristics, sites selection, and vehicle routing. Also, assessments can focus on sites (node) or roads (arcs) or both of them.

2. LITERATURE REVIEW

In this section, we review papers about humanitarian supply chain, and humanitarian routing papers. Çelik [5] illustrated the outcome of a general review of the literature on network reconstruction and improving humanitarian activities. Beiki et al. [6] considered a relief chain by proposing a novel location-routing model for assessing injured people under uncertainty. Oruc and Kara [7] presented a bi-objective mathematical model for collecting data from damaged areas on the transportation network. Huang et al. [8] concentrate on the assessment routing problem to evaluate demand points, and relief productivities after a disaster occurred. Kaviyani-Charati et al. [9] developed a multi-objective mathematical model to respond to disaster considering the location-transportation problem. Talarico et al. [10] illustrated an ambulance routing problem to response catastrophe. An integrated multi-objective model has been derived by Beiki et al. [11], which addressed the post-disaster challenges. Akbari et al. [12] scheduled relief teams to repair and rebuild the blocked routes. Nikoo et al. [13] studied the multi-objective model to demonstrate the optimal paths for emergency vehicles. Ostermeier and Hübner [14] studied a vehicle routing and selection problem of flexible compartment vehicles for food distribution. Nair et al. [15] presented a mathematical model for scheduling and routing. For further reading about disaster management and humanitarian logistics refer to literature [16-19]. This study presents a multi-objective model to maximize the gain from the assessment of areas and roads and the minimum cover of sites and roads. Two types of assessment teams, i.e., governmental, and Red Crescent teams are investigated. It is assumed that the governmental teams focus on the infrastructure and financial affairs, and the Red Crescent teams are more in charge of humanitarian and medical relief. The assessment times are assumed uncertain.

3. PROBLEM DESCRIPTION

For this purpose, teams and emergency agencies should be sent to affected areas. In this study, we consider two emergency teams such as Red Crescent and governmental assessment Team. We consider the following assumption for modeling:

- The division of scenarios is set up based on the intensity of the disaster and the relief items needs. We assume three scenarios: The first scenario for disaster with the least intensity and damage, the second scenario for disaster with an average level of severity and damage, the third scenario for the most severe and damage.
- The route of evaluation of each team starts from the origin node.
- Any team that leaves the origin node should return to it.
- Considering transportation budgets for teams.
- Nodes and roads have critical characteristics.
- Nodes are monitored by avoiding subtours but allowing total tours comprising the origin node.
- The assessment of each road and node is possible only by passing it.
- The limitation of the assessment time and the distance traveled have been considered.
- The assessment times are assumed to be fuzzy triangular numbers.

3. 1. Mathematical Modelling

This section illustrates the mathematical model for the post-disaster assessment routing problem:

$$\text{Max Obj1} = \sum_i p_i^s \sum_l A_{il}^s + \sum_{i<j} q_{ij}^s \sum_l z_{ijl}^s \tag{1}$$

$$\text{Max Obj2} = Z_1 \tag{2}$$

$$\text{Max Obj3} = Z_2 \tag{3}$$

$$Z_1 \leq \sum_{i \in N} \alpha_{ic}^s \left(\sum_l A_{il}^s\right) \quad \forall c \in C, s \tag{4}$$

$$Z_2 \leq \sum_{i<j} \alpha_{ijr}^s \left(\sum_l z_{ijl}^s\right) \quad \forall r \in R, s \tag{5}$$

$$\sum_l A_{il}^s = 1 \quad \forall i \in N, s \tag{6}$$

$$\sum_{i \in N} x_{oil}^{s} = \sum_{i \in N} x_{i0l}^{s} \quad \forall l, s \tag{7}$$

$$\sum_{\substack{i \in N \\ i \neq j}} x_{jil}^{s} + x_{oil}^{s} = A_{il}^{s} \quad \forall i \in N, l, s \tag{8}$$

$$\sum_{\substack{i \in N \\ i \neq j}} x_{ijl}^{s} + x_{i0l}^{s} = A_{il}^{s} \quad \forall i \in N, l, s \tag{9}$$

$$\sum_{i \in N} x_{0il}^{s} \leq 1 \quad \forall l, s \tag{10}$$

$$\sum_{i \in N} x_{i0l}^{s} \leq 1 \quad \forall l, s \tag{11}$$

$$x_{ijl}^{s} \leq E_{ij} \quad \forall (i,j) \in A, l, s \tag{12}$$

$$z_{ijl}^{s} \leq E_{ij} \quad \forall (i,j) \in A, l, s \tag{13}$$

$$z_{ijl}^{s} \leq x_{ijl}^{s} + x_{jil}^{s} \quad \forall (i,j), (j,i) \in A, l, s \tag{14}$$

$$z_{ijl}^{s} \geq \frac{x_{ijl}^{s} + x_{jil}^{s}}{2} \quad \forall (i,j), (j,i) \in A, l, s \tag{15}$$

$$\sum_{i \in N} \widetilde{ta}_{ik}^{s} A_{il}^{s} + \sum_{(i,j) \in A} \widetilde{ta}_{ijk}^{s} z_{ijk}^{s} \leq Tmax_{k}^{s} \ \forall l \in k, \mathrm{k}, \mathrm{s} \tag{16}$$

$$\sum_{i \in N} \widetilde{ta}_{ih}^{s} A_{il}^{s} + \sum_{(i,j) \in A} \widetilde{ta}_{ijh}^{s} z_{ijh}^{s} \leq Tmax_{h}^{s} \ \forall l \in h, \mathrm{h}, \mathrm{s} \tag{17}$$

$$\sum_{(i,j) \in A} d_{ij} x_{ijl}^{s} + \sum_{i} d_{oi} x_{0il}^{s} + \sum_{i} d_{oi} x_{i0l}^{s} \leq dmax_{k}^{s} \quad \forall l \in k, k, s \tag{18}$$

$$\sum_{(i,j) \in A} d_{ij} x_{ijl}^{s} + \sum_{i} d_{oi} x_{0il}^{s} + \sum_{i} d_{oi} x_{i0l}^{s} \leq dmax_{h}^{s} \quad \forall l \in h, h, s \tag{19}$$

$$\sum_{(i,j) \in A} \sum_{l=1}^{k} C_{l}^{s} d_{ij} x_{ijl}^{s} + \sum_{l \in h} \sum_{i} C_{l}^{s} d_{oi} x_{0il}^{s} + \sum_{l \in h} \sum_{i} C_{l}^{s} d_{oi} x_{i0l}^{s} \leq Bud_{GT}^{s} \ \forall \mathrm{s} \tag{20}$$

$$\sum_{(i,j) \in A} \sum_{l=k+1}^{k+h} C_{l}^{s} d_{ij} x_{ijl}^{s} + \sum_{l \in k} \sum_{i} C_{l}^{s} d_{oi} x_{0il}^{s} + \sum_{l \in k} \sum_{i} C_{l}^{s} d_{oi} x_{i0l}^{s} \leq Bud_{RT}^{s} \ \forall \mathrm{s} \tag{21}$$

$$u_i - u_j + N x_{ijl}^{s} \leq N - 1 \quad \forall \mathrm{i}, \mathrm{j}, \mathrm{i} \neq \mathrm{j}, \mathrm{l} \tag{22}$$

$$u_i, Z_1, Z_2 \geq 0 \quad \forall \mathrm{i} \tag{23}$$

$$x_{ijl}^{s}, A_{il}^{s}, z_{ijl}^{s} \in \{0,1\} \quad \forall \mathrm{i}, \mathrm{j}, \mathrm{l}, \mathrm{s} \tag{24}$$

The first objective function (1) maximizes the total value made by evaluating the sites and roads. The objective function (2) maximizes the minimum cover of sites, which is defined by constraint (4). The objective function (3) maximizes the minimum cover of roads, which is specified by constraint (5). Equation (6) ensures that each node must be assigned to one team. Equation (7) indicates that the number of paths that each team starts is equal to the number of paths that it ends. Equations (8) and (9) ensure that each node is immediately visited after the origin node or every other node, and after that, exactly one node is visited or it returns to the origin node. In addition, these constraints make the paths between the nodes and the assigned team to be made. Constraints (10) and (11) show that each team runs a maximum of one path. Constraints (12) and (13) guarantee that each arc traversed/assessed exists in the transportation network. constraints (14) and (15) show monitoring arc (i, j) by each team. Constraints (16) and (17) guarantee that sites and roads are evaluated during the allowed time, respectively. Constraints (18) and (19) display maximum distance in order to transfer from node i to node j. Constraints (20) and (21) show transportation budget constraints for the Governmental team and Red Crescent team, respectively. Constraint (22) is for eliminating subtours. Constraint (23) defines positive variables, and constraint (24) defines the binary variables.

4. SOLUTION METHODS

Regarding this issue that model has three objective functions, the LP-metric method is used to find the optimal solution in the GAMS software. The LP-metric method is one of the multi-objective methods that minimize the deviation of each objective function from its ideal point [20]. In this method, we can define the objective function as follows:

$$\min z = \sum w_i \left(\frac{z_i^* - z_i}{z_i^*} \right) \tag{25}$$

Also, we decided to solve the case study as large size problems with GOA that was proposed by Saremi et al. [21]. It is a meta-heuristic algorithm that is inspired by the swarm's behavior of the grasshoppers. The nature-inspired algorithms rationally divide the search process into two proclivities, namely exploration, and exploitation. Immature and mature grasshoppers move slowly with small steps, and abruptly with big steps, respectively, which leads to exploration and exploitation functions. Therefore, the grasshoppers perform these two abilities naturally, and by modeling this behavior, we have a new nature-inspired algorithm. So, we applied GOA to our problem as a powerful optimization algorithm. The GAMS and the GOA ran on an Intel(R) Core (TM)2 Duo CPU with 2.26 GHz and 3 GB RAM. It should be noted that we have considered three values for each uncertain parameter, namely, optimistic, pessimistic and most likely. To solve the model, mean of uncertain parameter are calculated with following formula [22]:

$$\mu = \frac{X_o + 4X_m + X_p}{6} \tag{26}$$

5. NUMERICAL EXAMPLE

5. 1. Deterministic Method In this section, the test problems are solved under the second scenario. We solved a small size and some test problem. First, we solved the small size problem by considering an origin node and three sites in GAMS. We also assumed four characteristics for sites and three characteristics for roads. In addition, the Red Crescent team has two assessment team members, and the Governmental team has three assessment team members. Pareto surface and Pareto front relating to this problem are depicted in Figures 1 and 2, respectively. We solved some problems with the proposed model by GAMS. The objective function values of all test problems are displayed in the Table 1.

5. 2. Meta-heuristic Method and Parameters Tuning We solved the test problems with the GOA to evaluate efficiency of it. First, we should adjust the GOA parameter such as the number of iteration (NI) and the population size of Grasshoppers (PG). For this purpose, the Taguchi method is used to adjust the parameters in the MINITAB software. We applied the L9(3**2) designing to adjust the GOA parameters. As you can see in the Figure 3, and given that the objective functions are all maximizing, the best Number of Iteration (NI) is 200 and the best Population size of Grasshoppers (PG) is 75. We solved again the test problems and obtain objective functions using the GOA to compare them with the optimal values computed by GAMS. Table 2 demonstrates the efficiency of the GOA.

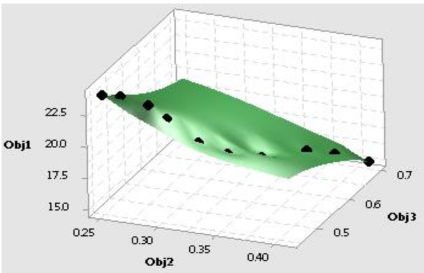

Figure 1. Pareto surface of small size problem

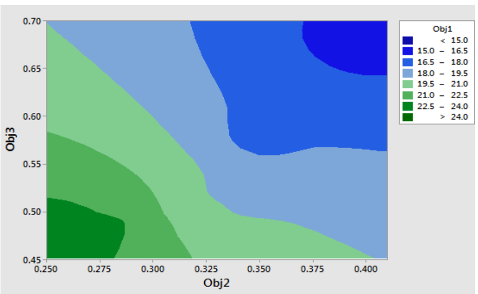

Figure 2. Pareto front of small size problem

TABLE 1. The objective values of test problems

Test problem	Node	Objective functions		
		Obj1	**Obj2**	**Obj3**
1	3	24	0.41	0.70
2	4	32	0.45	0.58
3	5	40	0.48	0.45

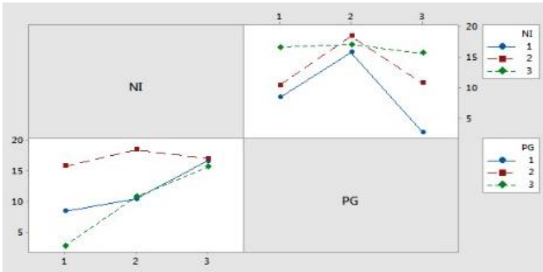

Figure 3. Mean diagrams from the Taguchi method

TABLE 2. The Comparison of exact and GOA

Test Problem	GOA			Gap %			
	Obj1	**Obj2**	**Obj3**	**O1**	**O2**	**O3**	**Average gap**
1	23.85	0.4078	0.689	0.62	0.54	1.49	0.88
2	31.79	0.4435	0.568	0.66	1.44	2.07	1.39
3	38.95	0.4699	0.444	2.62	2.10	1.24	1.99
Average				1.3	1.36	1.6	1.42

6. SENSITIVITY ANALYSIS

In this section, we changed some parameters to observe the objective functions behavior. Figure 4 displays the changes in all objective functions that are based on the changes in the total budget of the Red Crescent and the Governmental team. As shown in Figure 4, the changes on that parameter caused the first objective function to rise. When the assessment teams have more budget, they can visit and evaluate the more damaged area and roads. As a result, the second and third objective function increases too. Figure 5 shows the changes of all objective functions by changing the maximum time of the Red Crescent teams. As can be seen, the first objective function first increases with gentle gradients and then increases with a nearly steep slope. The second objective function increases with a gentle slope. The third objective function after passing a point grows slowly. We also changed the maximum evaluation time for the government team depicted in Figure 6.

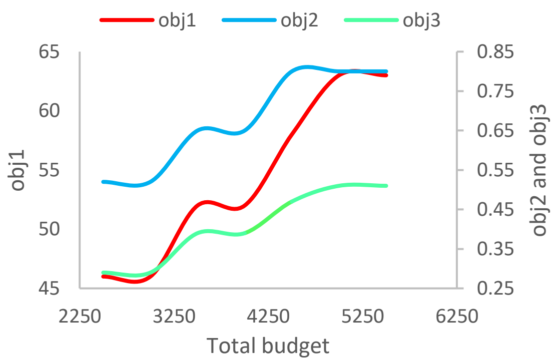

Figure 4. The impact of total budget changes of both Assessment Team on the objective functions

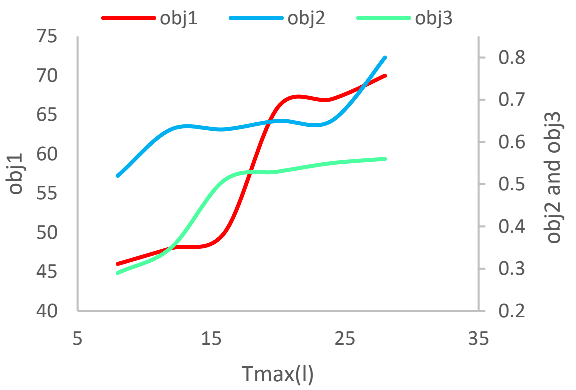

Figure 5. The impact of Tmax changes of the Red Crescent Team on the objective functions

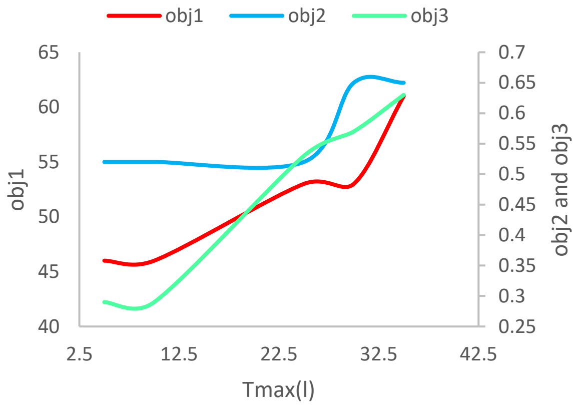

Figure 6. The impact of Tmax changes of the government Team on the objective functions

7. CASE STUDY

From mid-March to April 2019, widespread flash flooding occurred in large parts of Iran, most severely in Golestan, Khuzestan, Lorestan. In the present paper, we implement our model to Lorestan province. Heavy rains on 3 April, have entirely overwhelmed several towns in Lorestan. Figure 7 delineates Lorestan's map that damaged cities are marked with red circles, and the existing roads are marked with black lines. According to available data, we assume the flood as second scenario[1]. We consider Borujerd as the origin node, so there are sixteen roads between the damaged cities and the origin node. The cities in Lorestan may have rivers, forests, or be mountainous. Moreover, Lorestan has both smooth and mountainous roads. Therefore, we consider these characteristics for cities and roads. Figure 8 shows the Pareto front of the case study and Table 3 depicts the allocation of assessment teams.

[1] https://www.wunderground.com/cat6/Record-Floods-Iran-Kill-62-Cause-Over-1-Billion-Damage?cm_ven=cat6-widget

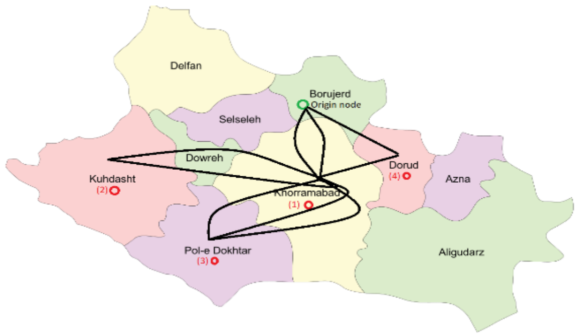

Figure 7. Lorestan's map

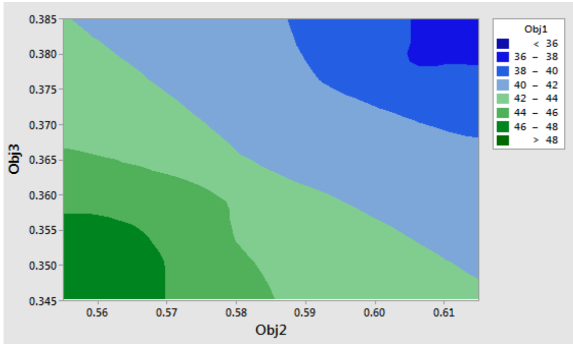

Figure 8. Pareto front of the case study

TABLE 3. The Allocation of assessment teams to nodes (RT: Red Crescent team, GT: Governmental team)

Node	Origin to i	i to j	j to origin	team
1	✓			RT3
2	✓		✓	GT2
3		✓	✓	RT3

8. CONCLUSION AND FUTURE RESEARCH

In this study, our focus was on the assessment of the conditions and requirements after the disaster. To this end, a multi-objective model is presented that can be useful for managing and planning assessment operation. The intended goals include maximizing the useful information gained from the assessment of cities and roads and the coverage of cities and roads, separately. We categorized disasters in different scenarios according to conditions and after-disaster damage and injuries. We solved the proposed model with the Lp-metric method and the GOA for several test problem. It was found that this algorithm has been efficiently applied and has useful application in real large-scale issues. Also, a case study in Lorestan, Iran is investigated. For future research, we can study a two-stage or three-stage problem. In addition to the different assessment teams that were considered in this research.

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Persian Abstract

چکیده

با توجه به اینکه حوادث غیرقابل اجتناب است و هر ساله افراد زیادی از آنها رنج می برند ، باید حوادث را مدیریت کنیم و به خوبی برای آنها برنامه ریزی کنیم تا تلفات و خسارات مالی را کاهش دهیم. یکی از اقداماتی که سازمانها پس از فاجعه باید انجام دهند ، ارزیابی شرایط و نیازهای مردم است. ارزیابی باید در اسرع وقت انجام شود و اطلاعات باید سریع جمع آوری شود. ما چند ویژگی برای سایت ها و جاده ها و دو تیم متفاوت برای ارزیابی و همچنین زمان ارزیابی غیر قطعی برای مدل سازی در نظر می گیریم. یک مدل برنامه ریزی عدد صحیح ترکیبی چند هدفه در این مقاله ارائه شده است. اولین تابع هدف حداکثر بهره حاصل از ارزیابی مناطق و جاده ها را به حداکثر می کند. تابع هدف های دوم و سوم پوشش را در مناطق و جاده های آسیب دیده به حداکثر می رسانند. ما از روش LP-متریک برای حل مسائل کوچک در نرم افزارگمز(GAMS) و الگوریتم بهینه سازی ملخ به عنوان یک الگوریتم فرا ابتکاری برای حل مسایل در اندازه های بزرگ استفاده می کنیم. نتایج عددی برای اثبات اعتبار و کارایی مدل ارائه شده است.