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FUZZY PLANNING MODEL FOR THE SHELTERS LOCATION AND VICTIMS EVACUATION IN THE DISASTER-STRICKEN ZONE

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Abstract. The fuzziness in the coverage, location, transportation and routing problems models is assumed to take place due to the lack of sufficient objective information on the disaster zone data. In evaluating the required parameters in the model, we use the knowledge and experience of experts (of route network dispatchers, etc.). Given the issues outlined above, we consider the fuzzy multi-objective emergency shelters location and victims evacuation problem (FMOESLVEP) in a disaster-stricken zone with the following objective functions: maximizing the total selection reliability index of opened shelters and minimizing the monotone expectation of total time for victims evacuation. These objective functions are novel and their construction and study are the basic tasks of the present work.

1. Introduction

Humanitarian logistics plays a significant role in facilitating disaster management processes by victims evacuating from affected areas to safe place and by planning, storing and distributing relief supplies to assist victims at the right time, right place and right cost ([8, 18]). Furthermore, humanitarian logistics also involves the selection of proper locations for relief facilities such as shelters, medical centers, distribution centers, warehouses, garbage dumps, etc. For the purposes of disaster response, the decision-making regarding shelters location-allocation is more important than the decision-making regarding other facilities ([11]). Given the issues outlined in this study, we consider a fuzzy multi-objective emergency shelters location and victims evacuation problems (FMOESLVEP) in the disaster-stricken zones with the humanitarian relief logistics response [2, 6, 7, 10, 12, 14–17, 19]. The study developed in this work proposes a multi-objective optimization model which aims to: (1) maximize the total selection reliability index of opened shelters; (2) minimize total costs, including fixed costs for shelters opening, victims transportation and service costs, (3) minimize monotone expectation of total time for victims evacuation and (4) minimize the number of open shelters. Objective functions (1) and (3) are novel and their construction and study are important tasks of this work. After realization of the proposed model, in our further research, we will demonstrate its applicability through a case study of shelters location-allocation and victims evacuation problem in response to the Monte-Carlo Simulation of flooding and Earthquake in some regions of Georgia.

In Section 2, we present the FMOESLVEP model formulation. The main conclusions, obtained results and future possible research directions can be found in Section 3.

2. Model Formulation

Given that the complex, flexible and dynamic nature of real logistical planning of emergency shelters location selection and victims evacuation in a disaster region produces a high degree of uncertainty in the modeling process, we should not expect that all the necessary information will be available at the onset of the problem.

Model Assumptions: 1) A network dispatcher visually receives information about roads and other damages through drones, helicopters or video-photo equipment of distance vision from the space. The dispatcher processes this information and divides the network into geographical zones according to the

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degree of road damage. Then dispatchers knowledge of these damages will be accumulated in their evaluations of the degrees of impossibility of vehicle movement between affected areas and shelters and other uncertain parameters. 2) The number of victims in each affected area is fixed and approximately evaluated by the network dispatcher in triangular fuzzy numbers (TFNs). 3) The locations of all affected areas and candidate shelters are fixed. 4) The victims in each affected area are evacuated to the selected shelters as a single unit, and not permitted to be separately assigned to different shelters. 5) The vehicles (aerial and terrestrial) used in the evacuation process are homogeneous. 6) The victims in each affected area are evacuated to the selected shelters by only one type of vehicle - aerial or terrestrial. 7) The velocity of a vehicle used in evacuation process is evaluated approximately. Traffic conditions are not taken into account.

Model Indices: I is a set of affected areas; J is a set of candidate shelters; h is an index to an aerial vehicle; g is an index to a terrestrial vehicle; p is an index to a vehicle, $p \in \{h, g\}$.

Model Parameters: d_{ij} is a distance between an affected area i and a candidate shelter j; c_j is a capacity of the candidate shelter j; $\widetilde{v}_i$ is a number of victims in affected area i evaluated in TFN. u_j is a fixed cost for opening the shelter j; $\widetilde{\delta}_j$ is a selection reliability index of the candidate shelter j evaluated in fuzzy values; $\widetilde{s}_{ij}$ is minimum acceptable distance between an affected area i and a shelter j evaluated in TFN; π_{ijp} is a degree of impossibility of vehicle moving between an affected area i and a shelter j, $p \in \{h, g\}$; M_p is a capacity of vehicle, $p \in \{h, g\}$. N_p is a number of vehicles for evacuation process, $p \in \{h, g\}$; $\widetilde{W}_p$ is maximum allowed time for evacuating the victims from an affected area i to a shelter j evaluated in TFN, $p \in \{h, g\}$; η_p is a constant coefficient of an expected transportation cost per kilometer per person per trip, $p \in \{h, g\}$; τ is a wage per person per day for hiring staff to work in the shelter; $\widetilde{\gamma}$ is a ratio of the required staff per victim evaluated in TFN; $\widetilde{T}$ is a duration of the disaster occurrence evaluated in TFN; $\widetilde{V}_p$ is a velocity of the vehicle used in evacuation process evaluated in TFN, $p \in \{h, g\}$.

Decision variables: $x_j = 1$ if a candidate shelter j is selected, otherwise, 0; $y_{ijp} = 1$ if an affected area i is assigned to shelter j by the transportation of type of vehicle $p \in \{h, g\}$; otherwise, 0; z_{ij} is a number of victims in area i that are assigned to shelter j.

Objective functions:

Objective 1.

$$\operatorname{Max} \widetilde{Z}_1 = \sum_{j \in J} \widetilde{\delta}_j x_j. \tag{1}$$

The first objective function (1) attempts to maximize the *total selection reliability index of open shelters* required to thoroughly serve the victims (fuzzy objective function).

Objective 2.

$$\operatorname{Min} \widetilde{Z}_2 = \sum_{j \in J} u_j x_j + \sum_{i \in I} \sum_{j \in J} \sum_{p \in \{h,g\}} \eta_p d_{ij} \widetilde{v}_i y_{ijp} + \frac{\tau \widetilde{T}}{\widetilde{\gamma}} \sum_{i \in I} \sum_{j \in J} z_{ij}. \tag{2}$$

The second objective function (2) attempts to minimize the *total fuzzy cost* that incorporates three terms (fuzzy objective function). The first term is a fixed cost for opening the shelters, where u_j is determined based on the cost for installing first necessary utility infrastructure. The second term is transportation cost regarding the distance and number of victims that are evacuated from affected area i to selected shelter j (uncertain parameter evaluated in the TFN). The third term is the service cost which is estimated as the number of required staff to work in shelters throughout a disaster (uncertain parameter evaluated in the TFN).

Objective 3.

$$\text{Min}\,\widetilde{Z}_3 = \int_0^1 \text{Pos}\left((i,j;p) : \frac{d_{ij}y_{ijp}}{\widetilde{V}_p} \cdot \frac{\widetilde{v}_i}{N_pM_p} \geq t\right)dt$$
$$= \sum_{k=1}^{|I\times J\times 2|} \left(\frac{d_{\sigma(k)}y_{\sigma(k)}}{\widetilde{V}_{p(k)}} \cdot \frac{\widetilde{\nu}_{\sigma(k)}}{N_{p(k)}M_{p(k)}}\left(\max_{(i,j,p)\in A_{\sigma(k)}}\{\pi_{ijp}\} - \max_{(i,j,p)\in A_{\sigma(k-1)}}\{\pi_{ijp}\}\right)\right). \tag{3}$$

The third objective function (3) seeks to minimize the *monotone expectation of total fuzzy time for evacuating victims* based on the distance between an affected area to a shelter, the number of victims that are displaced, the number of vehicles, the capacity of vehicles, the vehicles' speed during the disaster and impossibility levels of vehicle movement between affected areas and shelters (fuzzy objective function). In (3), dt is the Riemann integral's differential, Pos is a possibility distribution of impossibility degrees of vehicle movement between affected areas and shelters $\{\pi_{ijp}, i \in I, j \in J; p \in \{h,g\}\}$, $\frac{d_{\sigma(k)}y_{\sigma(k)}}{\widetilde{V}_{p(k)}} \cdot \frac{\widetilde{\nu}_{\sigma(k)}}{N_{p(k)}M_{p(k)}}$ is a k-th largest of values $\left\{\frac{d_{ij}y_{ijp}}{\widetilde{V}_p} \cdot \frac{\widetilde{v}_i}{N_pM_p}, i \in I, j \in J; p \in \{h,g\}\right\}$,

$$A_{\sigma(k)} = \left\{(i,j,p) : \frac{d_{ij}y_{ijp}}{\widetilde{V}_p} \cdot \frac{\widetilde{v}_i}{N_pM_p} \geq \frac{d_{\sigma(k)}y_{\sigma(k)}}{\widetilde{V}_{p(k)}} \cdot \frac{\widetilde{\nu}_{\sigma(k)}}{N_{p(k)}M_{p(k)}}\right\}, \quad A_{\sigma(0)} = \varnothing.$$

The value of this objective function coincides with the Choquet finite integral [4, 13] with respect to the possibility measure Pos [13].

Objective 4.

$$\text{Min}\,Z_3 = \sum_{j\in J} x_j. \tag{4}$$

The fourth objective function (4) aims to minimize the *number of open shelters required to serve the victims thoroughly.*

Subject to

$$\sum_{j\in J}\sum_{p\in\{h,g\}} y_{ijp} = 1, \ \ \forall i \in I. \tag{5}$$

Constraint (5) restricts that an affected area i must be assigned entirely only to a single shelter j by the transportation of only one type of vehicle (aerial or terrestrial).

$$y_{ijp} \leq x_j, \ \ \forall i \in I, \ j \in J; \ \ p \in \{h,g\}. \tag{6}$$

Constraint (6) stipulates that an affected area i must be assigned only to open shelters j.

$$d_{ij}y_{ijp} \geq \widetilde{s}_{ij}, \ \ \forall i \in I, \ j \in J; \ \ p \in \{h,g\}. \tag{7}$$

Constraint (7) requires that the distance between an affected area i to an assigned shelter j must be farther than the minimum acceptable distance $\widetilde{s}_{ij}$ (fuzzy constraint).

$$\frac{d_{ij}y_{ijp}}{\widetilde{V}_p} \cdot \frac{\widetilde{\nu}_i}{N_pM_p} \leq \widetilde{W}_p, \ \ \forall i \in I, \ j \in J; \ \ p \in \{h,g\}. \tag{8}$$

Constraint (8) limits the duration for evacuating victims from an affected area i to a shelter j to no longer than the maximum allowed time for evacuating $\widetilde{W}$ (fuzzy constraint).

$$\sum_{i\in I} z_{ij} \leq c_jx_j, \ \ \forall j \in J. \tag{9}$$

Constraint (9) restricts the number of assigned victims within the capacity of a selected shelter j.

$$x_j \in \{0,1\}, \ \ \forall j \in J. \tag{10}$$

Constraint (10) is a binary variable: x_j is 1 if a candidate shelter is selected to open; otherwise, it is 0.

$$z_{ij} \in \{0,1\}, \ \ \forall i \in I, \ j \in J. \tag{11}$$

Constraint (11) is a binary variable: z_{ij} is a number of victims in area i that are assigned to shelter j.

The presented model has been given with the assumption that the parameters are certain or evaluated by experts. In the real world, there is uncertainty in many of these parameters. For the solution of the constructed FMOESLVEP combinatorial optimization models of type (1)–(11) under fuzzy environments, we will propose in the future an epsilon-constraint ($\mathcal{E}$-constraint) method [1, 5, 9]. Based on the optimal solution of the FMOESLVEP, the Intelligent Support System for Emergency Shelters Location-Allocation Planning in disaster zones and evacuation of victims will be developed.

3. Conclusions

We assume the fuzziness in the constructed FMOESLVEP model relying on the fact that there is so sufficient amount of objective information on the disaster zone data. In evaluating the required parameters of the model, we have used the knowledge and experience of experts (of route network dispatchers, etc.). Given the issues outlined above, we consider a fuzzy multi-objective emergency shelters location and victims evacuation problem (FMOESLVEP) in the disaster-stricken zones. The objective functions (1) and (3) are novel and their construction and study are the important tasks of the work. The model takes into account the interactions between the decision-making attributes in the aggregation by the extended Choquet integral in the objective function (3). The realization scheme of the solution for the FMOESLVEP model will be developed.

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References

1. J.-F. Bérubé, M. Gendreau, J.-Y. Potvin, An exact ϵ-constraint method for bi-objective combinatorial optimization problems: application to the traveling salesman problem with profits. *European J. Oper. Res.* **194** (2009), no. 1, 39–50.
2. C. Boonmee, M. Arimura, T. Asada, Facility location optimization model for emergency humanitarian logistics. *International Journal of Disaster Risk Reduction* **24** (2017), 485–498. https://doi.org/10.1016/j.ijdrr.2017.01.017
3. C. Boonmee, N. Ikutomi, T. Asada, M. Arimura, Multi-model optimization for shelter-site selection: A case study in Banta municipality, Thailand. *Proc. of Infrastructure Planning in Japan Society of Civil Engineers* **53** (2016), 2175–2181. https://www.jstage.jst.go.jp/article/jscejipm/73/5/73_I_225/_pdf
4. G. Choquet, Theory of capacities. *Ann. Inst. Fourier (Grenoble)* **5** (1953/54), 131–295 (1955).
5. M. Ehrgott, *Multicriteria Optimization.* Second edition. Springer-Verlag, Berlin, 2005.
6. J. Hallak, M. Koyuncu, P. Mic, Determining shelter locations in conflict areas by multiobjective modeling: A case study in northern Syria. *International Journal of Disaster Risk Reduction* **9** (2019), no. 4, 38–53. https://doi.org/10.1016/j.ijdrr.2019.101202
7. A. Kumar, G. S. Kushwaha, Humanitarian logistics: A review and scientometric analysis. *Journal of Information Technology Research (JITR)* **11** (2018), no. 4, 53–71. https://www.igi-global.com/article/humanitarian-logistics/212609
8. W. Manopiniwes, T. Irohara, A review of relief supply chain optimization. *Industrial Engineering & Management Systems* **13** (2014), no. 1, 1–14.
9. G. Mavrotas, Effective implementation of the ϵ-constraint method in multi-objective mathematical programming problems. *Appl. Math. Comput.* **213** (2009), no. 2, 455–465.
10. P. Miç, M. Koyuncu, J. Hallak, Primary Health Care Center (PHCC) location-allocation with multi-objective modelling: A case study in Idleb, Syria. 25 pp. *Int. J. Environ. Res. Public Health* **2019**, 16(5), 811, 25 pp. https://doi.org/10.3390/ijerph16050811
11. E. Ozbay, Ö. Çavuş, B. Y. Kara, Shelter site location under multi-hazard scenarios. *Comput. Oper. Res.* **106** (2019), 102–118.
12. S. Y. Roh, Y. R. Shin, Y. J. Seo, The pre-positioned warehouse location selection for international humanitarian relief logistics. *The Asian Journal of Shipping and Logistics* **34** (2018), no. 4, 297–307. https://doi.org/10.1016/j.ajsl.2018.12.003
13. G. Sirbiladze, New Fuzzy Aggregation Operators Based on the Finite Choquet Integral — Application in the MADM Problem *International Journal of Information Technology & Decision Making* **15** (2016), no. 3, 517–551. https://doi.org/10.1142/S0219622016500127
14. G. Sirbiladze, H. Garg, B. Ghvaberidze, B. Matsaberidze, I. Khutsishvili, B. Midodashvili, Uncertainty modeling in multi-objective vehicle routing problem under extreme environment. *Artificial Intelligence Review* **55** (2022), no. 8, 6673–6707.

15. G. Sirbiladze, B. Ghvaberidze, B. Matsaberidze, B. Midodashvili, New fuzzy approach to facility location problem for extreme environment. *Journal of Intelligent & Fuzzy Systems* **37** (2019), no. 6, 7883–7893.
16. G. Sirbiladze, B. Matsaberidze, B. Ghvaberidze, B. Midodashvili, Fuzzy TOPSIS based selection index in the planning of emergency service facility location selection and goods transportation. *Journal of Intelligent & Fuzzy Systems* **41** (2021), no. 1, 1949–1962.
17. G. Sirbiladze, A. Sikharulidze, B. Matsaberidze, I. Khutsishvili, B. Ghvaberidze, Topsis approach to multi-objective emergency service facility location selection problem under Q-rung orthopair fuzzy information. *Trans. A. Razmadze Math. Inst.* **173** (2019), no. 3, 137–145.
18. L. Thomas, A. Kopczak, From logistics to supply chain management: The path forward in the humanitarian sector. *Fritz Institute* **15** (2005), no. 1, 1–15.
19. S. Tofighi, S. A. Torabi, S. A. Mansouri, Humanitarian logistics network design under mixed uncertainty. *European J. Oper. Res.* **250** (2016), no. 1, 239–250.

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