

A Fuzzy Multi-Objective Emergency Logistic Planning Model for the Selection of Shelters' Locations and Victims' Evacuation in Disaster-Affected Areas

Gia Sirbiladze*, Janusz Kacprzyk**, Jose Antonio Lozano§,
Bezhan Ghvaberidze*, Bidzina Midodashvili*,
Bidzina Matsaberidze*, Irina Khutsishvili*

* Department of Computer Sciences, Ivane Javakhishvili Tbilisi State University, Georgia

** Intelligent Systems Laboratory, Systems Research Institute, Polish Academy of Sciences, Poland

§ Department of Computer Science and Artificial Intelligence, University of the Basque Country, Spain

(Presented by Academy Member Ramaz Khurodze)

Abstract. The most important responsibilities of the emergency management system are the selecting shelters' location and ensuring the timely evacuation of victims from disaster-affected areas. Due to the lack of objective knowledge of disaster zone data, fuzziness in the models for the coverage, location, transportation, and routing problems is assumed. To assess the necessary parameters of the model, the knowledge and experience of branch experts is used. Given the aforementioned issues, fuzzy multi-objective emergency shelters' location and victims' evacuation problem (FMOESLVEP) is considered in the disaster-affected areas with response to humanitarian relief logistics. The model objectives include: 1) maximizing the total selection reliability index of opened shelters; 2) minimizing total costs, including fixed costs for opening shelters, victim transportation costs, and service costs; 3) minimizing monotonous waiting time for total evacuation of victims, and 4) minimizing the number of open shelters. Objective functions (1) and (3) are novel, and their development and study are important problems of this work. FMOESLVEP models are created for the different input fuzzy information. The models take into account the interactions between decision-making attributes by aggregating the extended Choquet integral. © 2025 Bull. Natl. Acad. Sci. Georg.

Keywords: humanitarian relief logistics, fuzzy multi-objective optimization, fuzzy facility location problem, fuzzy sets, fuzzy measure, possibility measure, Choquet integral, interactive MADM

Humanitarian logistics plays an important role in facilitating disaster management processes by evacuating victims from affected areas to a safe place, as well as by planning, storing, and distributing humanitarian aid to assist victims at the right time, in the right place, and at the right price (Manopiniwes & Irohara, 2014; Ozbay et al., 2019). Furthermore, humanitarian logistics involve selecting appropriate locations for aid facilities such as shelters, medical centers, distribution centers, warehouses, landfills, etc. For disaster

response, decision-making regarding the placement and distribution of shelters is more critical than decision-making regarding other facilities (Boonmee et al., 2016). In light of the aforementioned issues, we will consider a FMOESLVEP in the disaster-stricken zones with response to humanitarian relief logistics (Kacprzyk & Sirbiladze, 2022; Praneetpholklang & Huynh, 2020; Sirbiladze, 2021; Sirbiladze et al., 2022). This study proposes a multi-objective optimization model that aims at: 1) maximizing the total selection reliability index of opened shelters; 2) minimizing total costs, including fixed costs for opening shelters, victim trans-portion costs, and service costs; 3) minimizing monotonuous expectation of total time for victims' evacuation, and 4) minimizing the number of open shelters. Objective functions 1) and 3) are novel and their development and study issues are important tasks of this paper. The proposed complex fuzzy mathematical programming problem FMOESLVEP will be solved using the Epsilon Constraint technique (EC) (Mavrotas, 2009), Goal Programming (GP) (Kanoun et al., 2010), and Machine Learning Approach (ML) in this study framework.

Our paper (Sirbiladze et al., 2024) provided the design of the FMOESLVEP models. These models' formulations will be discussed in Section 2. Compliance of research methodology with research aims and objectives is presented in Section 3. The basic conclusions, obtained results, and future possible research directions are presented in Section 4.

Model Formulation

Model assumptions: 1) Information about road and other damage is visually received by the network dispatcher using drones, helicopters, or deep space vision technology. The dispatcher analyzes the information and determines the extent to which vehicles cannot move between affected areas and shelters, as well as other uncertainties. 2) The number of victims in each affected area is fixed and approximately evaluated by the networks' dispatcher in the triangular fuzzy numbers (TFNs) (Dubois & Prade, 1988). 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 the one type of vehicle – aerial or terrestrial. 7) The velocity of a vehicle used in evacuation process is evaluated approximately. Traffic conditions are not considered.

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 the candidate shelter j ; c_j is a capacity of the candidate shelter j ; $\tilde{v}_i$ is a number of victims in the affected area i evaluated in TFN; u_j is a fixed cost for opening the shelter j ; $\tilde{\delta}_j$ is a selection reliability index of the candidate shelter j evaluated in fuzzy values; $\tilde{s}_{ij}$ is the minimum acceptable distance between the affected area i and the 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, $p \in \{h, g\}$; $\tilde{W}_p$ is maximally allowed time for evacuating the victims from the affected area i to the shelter j evaluated in TFN, $p \in \{h, g\}$; η_p is a constant coefficient of expected transportation cost per kilometer per person per trip, $p \in \{h, g\}$; τ is a daily wage per person for hiring staff to work in

the shelter; $\tilde{\gamma}$ is a ratio of the required staff per victim evaluated in TFN; $\tilde{T}$ is a duration of the disaster occurrence evaluated in TFN; $\tilde{V}_p$ is a velocity of the vehicle using 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 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.

$$\text{Max } \tilde{Z}_1 = \sum_{j \in J} \tilde{\delta}_j x_j. \quad (1)$$

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.

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

The second objective function (2) attempts to minimize the total fuzzy cost that incorporates three terms (fuzzy objective function). The first term is the 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 the transportation cost regarding the distance and the number of victims that are evacuated from the affected area i to the 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.

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

The third objective function (3) seeks to minimize the monotonous expectation of total fuzzy time for evacuating victims based on the distance between the affected area to the 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 the possibility distribution (Dubois & Prade, 1988) of impossibility degrees of vehicle movement between the affected areas and

$$\left\{ \frac{d_{ij} y_{ijp}}{\tilde{V}_p} \cdot \frac{\tilde{v}_i}{N_p M_p}, i \in I, j \in J; p \in \{h, g\} \right\},$$

$$A_{\sigma(k)} = \left\{ (i, j, p) : \frac{d_{ij} y_{ijp}}{\tilde{V}_p} \cdot \frac{\tilde{v}_i}{N_p M_p} \geq \frac{d_{\sigma(k)} y_{\sigma(k)}}{\tilde{V}_{p(k)}} \cdot \frac{\tilde{v}_{\sigma(k)}}{N_{p(k)} M_{p(k)}} \right\}, A_{\sigma(0)} = \emptyset.$$

The value of this objective function coincides with the Choquet finite integral (Choquet, 1954) with respect to the possibility measure Pos .

Objective 4.

$$\text{Min } Z_3 = \sum_{j \in J} x_j. \quad (4)$$

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

Subject to

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

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

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

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

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

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

$$\frac{d_{ij} y_{ijp}}{\tilde{V}_p} \cdot \frac{\tilde{v}_i}{N_p M_p} \leq \tilde{W}_p, \quad \forall i \in I, j \in J; p \in \{h, g\}. \quad (8)$$

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 $\tilde{W}$ (fuzzy constraint).

$$\sum_{i \in I} z_{ij} \leq c_j x_j, \quad \forall j \in J. \quad (9)$$

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

$$x_j \in \{0, 1\}, \quad \forall j \in J. \quad (10)$$

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

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

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

The proposed model assumes that the parameters are known or have been evaluated by experts. In reality, many of these parameters are uncertain. Therefore, the model will be developed under uncertainty to bring it closer to real conditions. The model's linearization and robust optimization approaches will be used in our future research to develop the work tasks.

Compliance of Research Methodology with Research Aims and Objectives

The task of this section is to develop a method for estimating the innovative object function (1) coefficients, shelters selection reliability indexes – $\tilde{\delta}_j, j \in J$. A multi-attribute decision-making approach for location selection problem for shelters (Shelter Sites (SSs)) under uncertainty and extreme environment is focused and a fuzzy approach to model decision-making parameters will be used. To decide on the location of SSs,

it is assumed that a set of candidate shelter sites already exists. This set is denoted by J , where SSs can be located. Let $S = \{s_1, s_2, \dots, s_n\}$ be the set of all attributes (benefit or cost attributes, cost attributes are transformed into benefit ones), which define SSs selection. Let $W = \{w_1, w_2, \dots, w_n\}$ be the weights of attributes, evaluated by the experts. For each emergency expert e_k from the group of experts $E = \{e_1, e_2, \dots, e_t\}$, let r_{ji}^k be the rating (utility, degree of membership, etc.) of his evaluation for each candidate SS j , $j \in J$, with respect to each attribute s_i , ($i = 1, \dots, n$). For the expert e_k we construct binary relation $\tilde{R}_k = \{\tilde{r}_{ji}^k, j \in J; i = 1, \dots, n\}$, elements of which will be represented in triangular fuzzy numbers (Dubois & Prade, 1988; Kacprzyk et al., 2019; Kacprzyk & Sirbiladze, 2022), triangular intuitionistic or Pythagorean or q ($q \geq 1$)-rung orthopair fuzzy values or triangular q ($q \geq 1$)-rung orthopair fuzzy values (Garg et al., 2021; Sirbiladze, 2020; Sirbiladze et al., 2019; Yager, 2016), or q ($q \geq 1$)-rung picture linguistic values (Sirbiladze, 2021).

On orthopair fuzzy sets: Orthopair fuzzy sets are the fuzzy sets, in which the membership grades of an element x are pairs of values from the unit interval, $\{A^+(x), A^-(x)\}$, one of which indicates support for membership in the fuzzy set and the other support against membership. An important pragmatic implication of this, as noted by Yager (2016), is that this provides systems modelers more freedom, it is less restrictive, in the allowable membership grades. For q -rung orthopair fuzzy sets the constraining relationship between the support for and against membership is that $(A^+(x))^q + (A^-(x))^q \leq 1$ with $q \geq 1$. Note that as the rung $q \geq 1$ increases, the space of acceptable orthopairs increases, the more orthopairs satisfy the bounding constraint, and thus, the experts are given more freedom in expressing their belief about membership grade.

Based on the work authors' recent results on the decision-making aggregation operators for triangular, intuitionistic or q -rung orthopair fuzzy environments (Garg et al., 2021; Sirbiladze, 2016, 2020; Sirbiladze et al., 2021; Sirbiladze et al., 2019) our task in future will be to build fuzzy multi-attribute decision-making method for more general fuzzy arguments. The method for each candidate SS will aggregate presented objective and subjective data into scalar value – shelter site's selection reliability index. New methodology will be constructed in our future tasks for triangular intuitionistic, Pythagorean or q ($q \geq 1$)-rung orthopair fuzzy values, q ($q \geq 1$)-rung picture linguistic values. Formally for triangular q ($q \geq 1$)-rung orthopair or fuzzy picture linguistic values this aggregation can be represented as:

$$\tilde{\delta}_j = \text{Agregg}(W, [\tilde{R}_1]_i, \dots, [\tilde{R}_t]_i), \quad j \in J,$$

where *Agregg* is some multi-attribute decision-making (MADM) fuzzy aggregation operator; $\tilde{\delta}_j$ is called a selection reliability index of the j -th SS. In general case, *Agregg* is an operator, defined on the concrete lattices $\hat{\Psi}$ of above presented fuzzy values: $\text{Agregg} := F(\tilde{r}_1, \tilde{r}_2, \dots, \tilde{r}_n): (\hat{\Psi})^n \Rightarrow \hat{\Psi}$, where $\tilde{r}_i$, $i = 1, \dots, n$ are experts' evaluations on the attributes set $S = \{s_1, s_2, \dots, s_n\}$ for some candidate shelter site. To simplify our future representations only case of TFNs will be considered – $\hat{\Psi} = \Psi_0^+$. For real multi-criteria decision-making problems such as fuzzy shelters' location problem, there is a phenomenon ensuring that there exists some degree of inter-dependent or interactive characteristics and non-additivity between attributes (Kojadinovic, 2002). For a decision problem, subjective assessments by emergency managers always generate non-additivity. Thus, it is impossible to use linear and additive aggregations.

On the optimal construction of the *Agregg* operator for the definition of reliability index – $\tilde{\delta}_i$. Our approach in mentioned tasks will be different from all and this means that we will use the second pole of representation of the expert information – measure of the information uncertainty – using fuzzy measure with the first pole – imprecision of data (presented by fuzzy values). Sugeno (1974) introduced the

definition of a non-additive (fuzzy) measure that only requires monotonicity, instead of additivity. To the case of a finite referential we adapted the definition of a fuzzy measure as follows:

Definition 1: Let $S = \{s_1, s_2, \dots, s_n\}$ be a finite set and μ be a set function $\mu: 2^S \rightarrow [0, 1]$. μ is said to be a fuzzy measure (FM) on S if it satisfies:

$$(i) \quad \mu(\emptyset) = 0; \quad \mu(S) = 1; \quad (ii) \quad \forall A, B \subseteq S \quad \text{if } A \subseteq B, \text{ then } \mu(A) \leq \mu(B).$$

The possible orderings of the elements of S are given by the permutations of a set with n elements, which form the group S_n . Now we consider a definition of associated probabilities (Sirbiladze, 2020) induced by a fuzzy measure on the group S_n .

Definition 2: The probability functions λ_σ defined by

$$\begin{aligned} \lambda_\sigma(s_{\sigma(1)}) &= \mu(\{s_{\sigma(1)}\}), \dots, \lambda_\sigma(s_{\sigma(i)}) = \mu(\{s_{\sigma(1)}, \dots, s_{\sigma(i)}\}) - \mu(\{s_{\sigma(1)}, \dots, s_{\sigma(i-1)}\}), \dots, \\ \lambda_\sigma(s_{\sigma(n)}) &= 1 - \mu(\{s_{\sigma(1)}, \dots, s_{\sigma(n-1)}\}), \mu(\{s_{\sigma(0)}\}) \equiv 0 \end{aligned}$$

for each $\sigma = (\sigma(1), \sigma(2), \dots, \sigma(n)) \in S_n$, are called the associated probabilities and the set of all of them form the Associated Probability Class (APC) - $\{\lambda_\sigma\}_{\sigma \in S_n}$ of a fuzzy measure μ .

Fuzzy measure proved to be the most effective tool for modeling phenomena of interaction (Kacprzyk & Sirbiladze, 2022; Sirbiladze, 2020) and dealing with decision problems, in which the probability is replaced with the fuzzy measure. A finite Choquet integral is the most typical aggregation instrument which condenses interactions between the attributes into the scalar value for a possible decision-making alternative. We will use extensions of Choquet integral for the definition of candidate shelter site selection reliability index for triangular q ($q \geq 1$)-rung orthopair fuzzy environments (Intuitionistic, Pythagorean and so on).

Definition 3 (Choquet, 1954): Assume μ is a fuzzy measure on the attributes set S and we have a variable of expert evaluations $r: S \Rightarrow R_0^+$ such that $r(s_i) \equiv r_i \geq 0$, $i = 1, 2, \dots, n$. Then the aggregation

$$\begin{aligned} CI(r_1, r_2, \dots, r_n) &= \sum_{j=1}^n \lambda_j r_{i(j)}, \\ \lambda_l &= \mu(\{s_{i(1)}, \dots, s_{i(l)}\}) - \mu(\{s_{i(1)}, \dots, s_{i(l-1)}\}), l = 1, \dots, n; \quad \mu(\{s_{i(0)}\}) \equiv 0, \end{aligned}$$

is called the discrete Choquet integral (CI) with respect to the fuzzy measure g where in the proceeding $i(\cdot)$ is index function such that $r_{i(l)}$ is the l -th largest of the $\{r_i\}_{i=1}^n$. It is clear that $\sum_{l=1}^n \lambda_l = 1$, $\lambda_l \geq 0$.

Choquet integral's type operators not only consider the importance of the elements or their ordered position, but also reflect the correlations or interactions among some combinations of attributes. Though many aggregation operators based on Choquet aggregation operator have been developed under intuitionistic fuzzy environment, there is still an issue that needs to be addressed: Choquet integral does not reflect the overall interactions among all combinations of attributes (Sirbiladze, 2016). It seems from the definition that CI operator reflects the overall interaction only among the elements' combinations of the consonant structure of attributes:

$$\{s_{i(1)}\}, \{s_{i(1)}, s_{i(2)}\}, \dots, \{s_{i(1)}, \dots, s_{i(n)}\}.$$

Hence, the work authors' goal in their last works was to create new aggregation operators based on the probability presentations of a fuzzy measure (Associated Probability Class (APC)) for triangular and intuitionistic fuzzy environments. The developed operators take into account the overall interactions among all combinations of the factors (attributes). Correctness of the extensions of the finite Choquet integral were proved

for the fuzzy measure – capacity of order two (Sirbiladze, 2020). In the future tasks, this approach for triangular q ($q \geq 1$)-rung orthopair fuzzy and picture environments will be developed (Sirbiladze, 2020, 2021). Investigation of Choquet type aggregation operators for generalized orthopair fuzzy arguments will give the opportunity to define candidate shelter site selection reliability index in the FMOESLVEP. It is giving us more convincing aggregation tool, both to evaluate parameters and construct new objective functions in the FMOESLVEP for selection of SSs. As the fuzzy measure, k -order additive fuzzy measure theory will be used (Kojadinovic, 2002) in decision-making aggregation operators under different fuzzy environments. The authors of this project (Sirbiladze, 2020) demonstrated the linear connection between two-order additive fuzzy measure's values, attributes interaction indexes and Shapley values:

$$\mu(\{s_{\sigma(1)}, \dots, s_{\sigma(i)}\}) = \sum_{l=1}^i I_{\sigma(l)} - (1/2) \cdot \sum_{k \in N_{\sigma(i)}} \sum_{l=1}^i I_{\sigma(i)l}, \quad \forall \sigma = \{\sigma(1), \dots, \sigma(n)\} \in S_n, \quad i = 1, \dots, n,$$

where $N_{\sigma(i)}$ denotes an index subset $N_{\sigma(i)} = \{1, \dots, n\} \setminus \{\sigma(1), \dots, \sigma(i)\}$, $I_{\sigma(i)}$ is the Shapley value of an attribute $s_i \in S$ and $I_{\sigma(i)l}$ is the interaction index of two attributes $s_i, s_j \in S$ (S_n is a set of all permutation of indexes from 1 to n). Using definition of the associated probabilities of a FM (Def. 2), connections between associated probabilities, Shapley values and interaction indexes of attributes are obtained:

$$\lambda_{\sigma}(s_{\sigma(i)}) = I_{\sigma(i)} + (1/2) \cdot \sum_{l=1}^{i-1} I_{\sigma(i)\sigma(l)} - (1/2) \cdot \sum_{l=i+1}^n I_{\sigma(i)\sigma(l)}.$$

In the work tasks this identification problem will be solved when interaction indexes and Shapley values are evaluated by experts in triangular q -rung orthopair or other fuzzy values. Based on identified fuzzy measure, the extensions of a Choquet integral type aggregation will reflect the overall interactions among all combinations of attributes.

During the subsequent future researches, for the solution of constructed FMOESLVEP combinatorial optimization models of type (1)-(11) under different fuzzy environments, an epsilon-constraint (ε -constraint) method will be proposed (Mavrotas, 2009). General ε -constraint approach in multi-criteria optimization problems are given in Ehrgott's work (Ehrgott, 2005).

Conclusions

We consider a fuzzy multi-objective emergency shelters' location selection and victims' evacuation planning problem (FMOESLVEP) in the disaster-stricken zones. Two of the four objective functions of the model, namely, (a) maximizing the total selection reliability index of opened shelters, and (b) minimizing the monotonuous expectation of total time for victims' evacuation, are novel, and issues of their development and study are important tasks of this work. The FMOESLVEP models consider the interactions between decision-making attributes by aggregating the extended Choquet integral. Based on the obtained results, the Intelligent Support System for the FMOESLVEP in disaster zones will be developed in our future research.

Acknowledgements

The research was funded by the Shota Rustaveli National Science Foundation of Georgia (SRNSF), grant number [FR-22-969].

ინფორმატიკა

ფაზი-მრავალკრიტერიუმიანი გადაუდებელი ლოგისტიკის დაგეგმვის მოდელი თავშესაფრების ადგილმდებარეობის შერჩევისა და დაზარალებულთა ევაკუაციისთვის კატასტროფის რაიონებში

გ. სირბილაძე*, ი. კაქპრუიკი**, ჟ. ა. ლოზანო§, ბ. დვაბერიძე*,
ბ. მიდოდაშვილი*, ბ. მაცაბერიძე*, ი. ხუციშვილი*

* ივანე ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტი, კომპიუტერულ მეცნიერებათა ფაკულტეტი, საქართველო

** პოლონეთის მეცნიერებათა აკადემია, სისტემების კვლევითი ინსტიტუტი, ინტელექტუალური სისტემების ლაბორატორია, პოლონეთი

§ ბასკეთის ქვეყნის უნივერსიტეტი, კომპიუტერული მეცნიერებისა და ხელოვნური ინტელექტის დეპარტამენტი, ესპანეთი

(წარმოდგენილია აკადემიის წევრის რ. ხუროძის მიერ)

საგანგებო სიტუაციების მართვის სისტემის ყველაზე მნიშვნელოვან ამოცანებს წარმოადგენს თავშესაფრების ადგილმდებარეობის შერჩევა და სტიქიით დაზარალებული რეგიონებიდან მათი თავშესაფრებში დროული ევაკუაციის უზრუნველყოფა. კატასტროფის არეალის მონაცემების შესახებ ობიექტური ცოდნის ნაკლებობის გამო ჩვენ ვვარაუდობთ, ფაზი-დაშვებას დაფარვის, ადგილმდებარეობის შერჩევის, ტრანსპორტირებისა და მარშრუტიზაციის ამოცანების მოდელში. მოდელისთვის საჭირო პარამეტრების შესაფასებლად გამოყენებულია დარგის ექსპერტების ცოდნა და გამოცდილება. ზემოაღნიშნულის გათვალისწინებით, ჩვენ განვიხილავთ კატასტროფის შედეგად დაზარალებულ რაიონებში გადაუდებელი ფაზი-მრავალკრიტერიუმიანი თავშესაფრების განთავსებისა და დაზარალებულთა ევაკუაციის ამოცანას (FMOESLVEP). მოდელის ოთხი მიზნის ფუნქციიდან ორი, კერძოდ, (ა) გახსნილი თავშესაფრების მთლიანი შერჩევის სანდოობის ინდექსის მაქსიმიზაცია და (ბ) დაზარალებულთა ევაკუაციის მთლიანი დროის მონიტორინგი მოლოდინის მინიმუმამდე შემცირება ახალია და მათი აგებისა და შესწავლის საკითხები ნაშრომის ერთ-ერთი მნიშვნელოვანი ამოცანაა. FMOESLVEP მოდელები შემუშავებულია სხვადასხვა სახის შემავალი ფაზი-ინფორმაციისთვის. მოდელები ითვალისწინებს გადაწყვეტილების მიღების ატრიბუტებს შორის ურთიერთქმედებას გავრცობილი შოკის ინტეგრალით აგრეგირების გზით.

REFERENCES

- Boonmee, C., Ikutomi, N., Asada, T., & Arimura, M. (2016). 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, 2175-2181.
- Choquet, G. (1954). Theory of capacities. *Ann. Inst. Fourier*, 5, 131-295.
- Dubois, D., & Prade, H. (1988). *Possibility theory: an approach to computerized processing of uncertainty*. Plenum Press, New-York.
- Ehrgott, M. (2005). *Multicriteria optimization*. Berlin: Springer.
- Garg, H., Sirbiladze, G., Zeeshan, Ali Z., & Mahmood, T. (2021). Hammy mean operators based on complex q-rung orthopair fuzzy setting and their application in multi-attribute decision making. *Mathematics*, 9(18), 2312.
- Kacprzyk, J., Kondratenko, Y. P., Merigó, J. M., Hormazabal, J. H., Sirbiladze, G., & Gil-Lafuente, A. M. (2019). A Status Quo biased multistage decision model under fuzzy information. *Studies in Systems, Decision and Control*, 203, 201-226.
- Kacprzyk, J., & Sirbiladze, G. (2022). Associated fuzzy probabilities in MADM with interacting attributes. Application in multi-objective facility location selection problem. *International Journal of Information Technology & Decision Making*, 21(4), 1155-1188.
- Kanoun, I., Chabchoub, H., & Aouni, B. (2010). Goal programming model for fire and emergency service facilities site selection. *INFOR*, 48(3), 143-153.
- Kojadinovic, I. (2002). Modeling interaction phenomena using fuzzy measures: On the notions of interaction and independence. *Fuzzy Sets and Systems*, 135, 317-340.
- Manopiniwes, W., & Irohara, T. (2014). A review of relief supply chain optimization. *Industrial Engineering and Management Systems*, 13(1), 1-14.
- Mavrotas, G. (2009). Effective implementation of the Epsilon-Constraint method in multi-objective mathematical programming problems. *Applied Mathematics and Computation*, 213(2), 455-465.
- Ozbay, E., Cavus, Ö., & Kara, B.Y. (2019). Shelter site location under multi-hazard scenarios. *Computers and Operations Research*, 106, 102-118.
- Praneetpholkrang, P., & Huynh, V. N. (2020). Shelter site selection and allocation model for efficient response to humanitarian relief logistics. In: Springer, Lecture notes in logistics, *Dynamics in logistics*, 309-318.
- Sirbiladze, G. (2016). New fuzzy aggregation operators based on the finite choquet integral: Application in the MADM problem. *International Journal of Information Technology & Decision Making*, 15(3), 517-551.
- Sirbiladze, G. (2020). Associated probabilities' aggregations in interactive MADM for q-rung orthopair fuzzy discrimination environment. *International Journal of Intelligent Systems*, 35(3), 335-372.
- Sirbiladze, G. (2021). Associated probabilities in interactive MADM under discrimination q-rung picture linguistic environment. *Mathematics*, 9(18), 2337.
- Sirbiladze, G., Garg, H., Ghvaberidze, B., Matsaberidze, B., Khutsishvili, I., & Midodashvili, B. (2022). Uncertainty modeling in multi-objective vehicle routing problem under extreme environment. *Artificial Intelligence Review*, 55(8), 6673-6707.
- Sirbiladze, G., Kacprzyk, J., Khurodze, R., Ghvaberidze, B., Midodashvili, B., Matsaberidze, B., & Khutsishvili, I. (2024). Humanitarian relief logistics fuzzy planning model for the shelters location selection and evacuation of victims in the disaster region. *Bull. Georg. Natl. Acad. Sci.*, 18(2), 44-51.
- Sirbiladze, G., Matsaberidze, B., Ghvaberidze, B., Midodashvili, B., & Mikadze, D. (2021). Fuzzy TOPSIS based selection index in the planning of emergency service facility location selection and goods transportation. *Journal of Intelligent & Fuzzy Systems*, 41(1), 1949-1962.
- Sirbiladze, G., Sikharulidze, A., Matsaberidze, B., Khutsishvili, I., & Ghvaberidze, B. (2019). TOPSIS approach to multi-objective emergency service facility location selection problem under q-rung orthopair fuzzy information. *Transactions of A. Razmadze Mathematical Institute*, 173(3), 137-145.
- Sugeno, M. (1974). *Theory of Fuzzy Integral and its applications*. Thesis (PhD). Tokyo Institute of Technology, Tokyo.
- Yager, R. R. (2016). Generalized orthopair fuzzy sets. *IEEE Transactions on Fuzzy Systems*, 1063-6706.

Received May, 2025