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Informatics

Humanitarian Relief Logistics Fuzzy Planning Model for the Shelters Location Selection and Evacuation of Victims in the Disaster Region

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Recent years have seen significant growth in human life losses and material damages caused by natural disasters, which can cause serious and long-term damage to countries. When the suitable candidate places of shelters (Shelter Sites (SSs)) location are selected, a group of sites should be selected from them that in some sense better meet the requirements such as: maximizing the reliability index of the selection of shelters, minimizing costs, maximizing evacuation coverage, etc. In such cases, the use of intelligent support technologies is very important for the fast and optimal service of location-transportation-routing in emergencies, so that the new losses caused by repeated extreme events are avoided. Ensuring the timely evacuation of victims from disaster-affected areas is one of the most important tasks of the emergency management system. We assume fuzziness in the covering, location, transportation, and routing problems' models, because there is insufficient amount of objective information on disaster zone data. In evaluating the required parameters in the model, we use the knowledge and experience of experts (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 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 of monotone expectation of total time for victims' evacuation, and (4) minimizing the number of open shelters. Objective functions (1) and (3) are novel and their construction and study issues are one of the important tasks of the project. FMOESLVEP models are developed for the different input fuzzy information. The models take into account the interactions between decision making attributes by aggregating the extended Choquet integral. The realization scheme of the solution for the FMOESLVEP models is given. *© 2024 Bull. Georg. Natl. Acad. Sci.*

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

Recent years have seen significant growth in human life losses and material damages caused by natural disasters such as earthquakes, flooding, tsunamis, tornadoes, which can cause serious and long-term damage to countries. This prompted researchers from different fields to investigate intensively the challenges of emergency management.

Processes in emergency after disaster should be planned in such a manner that they can respond to the needs of victims as fast as possible. Humanitarian logistics plays a significant role in facilitating disaster management processes by evacuating victims from affectedareas to safe places, and by planning, storing, and distributing reliefsupplies to assist victims at the right time, right place, and right cost [1]. Furthermore, humanitarian logistics also involves selecting proper locations for relief facilities such as shelters, medical centers, distribution centers, warehouses, garbage dumps, etc. For the purposes of disaster response, decision-making regarding shelters location-allocation is more important than decision-making regarding other facilities [2].

Some studies propose single-objective or multi-objective optimization models in efforts to improve efficiency of humanitarian relief logistics. These facilities include shelters, medical centers, warehouses, distribution centers, diseasecontrol and prevention, and waste disposal [3].

The novelty of the model given in this work consists in its in-depth details which adequately reflects the actual emergency. We will consider a fuzzy multi-objective emergency shelters location and victims evacuation problem (FMOESLVEP) in the disaster-stricken zones with response to humanitarian relief logistics [4-7]. This study developed in the work proposes a multi-objective optimization model which aims at (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 of monotone expectation of total time for victims' evacuation, and (4) minimizing the number of open shelters. Objective functions (1) and (3) are novel and their construction and study issues are one of the important tasks of the project. In the scope of this work, the Epsilon Constraint method (EC) [8], Goal Programming (GP) [9] and Machine Learning Approach (ML) will be presented for solution of the proposed complex fuzzy mathematical programming problem – FMOESLVEP.

Model Formulation

The considerable parameters, including minimum acceptable distance between each affected area to the candidate shelter site, and constant coefficient of transportation cost are predetermined as follows:

Minimum acceptable distance ($\tilde{s}_{ij}$): means the minimum distance between affected area i and candidate shelter j, which helps decision-makers avoid selecting shelters located closer than acceptable distance to affected areas. This is because the nearest shelters may not be safe from the same disaster. Initially, each affected area is divided into an equal grid of one-kilometer increments. Therefore, $\tilde{s}_{ij}$ is an uncertain parameter, which can be simply represented by the triangular fuzzy number (TFN, [10]). $\tilde{s}_{ij}$ is represented by Eq. (1), where the diagonal length line of rectangle D is multiplied by the ratio of approximate number of victims in each affected area $\tilde{v}_i$ (fuzzy parameter, presented also in TFNs) to population density - $p\tilde{d}$ square kilometer:

$$\tilde{s}_{ij} = D \cdot \frac{\tilde{v}_i}{p\tilde{d}} . \qquad (1)$$

Constant coefficient of transportation cost (η): The constant transportation cost per person per kilometer in each trip is denoted by η. Herein, η is estimated as fuel cost per liter divided by the product of fuel consumption rate and a vehicle's capacity of passengers per trip, as illustrated in Eq. ($1'$):

$$\eta = \frac{Fuel\ cost}{Fuel\ consumption\ rate \cdot Vehicle's\ capasity}. \qquad (1')$$

Assumptions

- A network dispatcher visually receives information about road and other damages through drones, helicopters, or video-photo equipment of distance vision from space. The dispatcher processes this information and divides the network into geographical zones according to the degree of road damage. Dispatchers' knowledge of these damages will then be accumulated in their evaluations to the degrees of impossibility of vehicle movement between affected areas and shelters and other uncertain parameters.
- The number of victims in each affected area is fixed and approximately evaluated by the networks' dispatcher in TFNs.
- The locations of all affected areas and candidate shelters are fixed.
- 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.
- The vehicles (aerial and terrestrial) used in the evacuation process are homogeneous.
- The victims in each affected area are evacuated to the selected shelters by the one type of vehicle - aerial or terrestrial.
- The velocity of a vehicle used in evacuation process is evaluated approximately. Traffic conditions are not considered.

Indices

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

Parameters

d_{ij} − distance between affected area i and candidate shelter j; c_j − capacity of the candidate shelter j; $\tilde{v}_i$ − number of victims in affected area i evaluated in TFN;

u_j − fixed cost for opening the shelter j; $\tilde{\delta}_j$ − selection reliability index of the candidate shelter j evaluated in fuzzy values; $\tilde{s}_{ij}$ − minimum acceptable distance between affected area i and shelter j evaluated in TFN; π_{ijp} − degree of impossibility of vehicle moving between affected area i and shelter j , $p \in \{h,g\}$. M_p − capacity of vehicle, $p \in \{h,g\}$; N_p − number of vehicles for evacuation process, $p \in \{h,g\}$;

$\tilde{W}_p$ − maximum allowed time for evacuating the victims from affected area i to shelter j evaluated in TFN, $p \in \{h,g\}$; η_p − constant coefficient of expected transportation cost per kilometer per person per trip, $p \in \{h,g\}$; τ − wage per person per day for hiring staff to work in the shelter; $\tilde{\gamma}$ − ratio of the required staff per victim evaluated in TFN;

$\tilde{T}$ − duration of the disaster occurrence evaluated in TFN; $\tilde{V}_p$ − velocity of the vehicle using in evacuation process evaluated in TFN, $p \in \{h,g\}$.

Decision Variables

x_j = 1, if 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} – number of victims in area i that are assigned to shelter j.

Objective Functions

Objective 1.

$$Max\ \tilde{Z}_1 = \sum_{j \in J} \tilde{\delta}_j x_j\ . \tag{2}$$

The first objective function (2) attempts to maximize the *total selection reliability index of open shelters* required to thoroughly serve the victims (fuzzy objective function).

Objective 2.

$$Min\ \tilde{Z}_2 = \sum_{j \in J} u_j x_j + \sum_{i \in I} \sum_{j \in J} \sum_{p \in \{h,g\}} \eta_p d_{ij} \tilde{v}_i y_{ijp} + \frac{\tau \tilde{T}}{\tilde{\gamma}} \sum_{i \in I} \sum_{j \in J} z_{ij}\ . \tag{3}$$

The second objective function (3) attempts to minimize the *total fuzzy cost* that incorporates three terms (fuzzy objective function). The first term is 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.

$$\begin{aligned} Min\ \tilde{Z}_3 &= \int_0^1 Pos\left((i, j; p) : \frac{d_{ij} y_{ijp}}{\tilde{V}_p} \cdot \frac{\tilde{v}_i}{N_p M_p} \geq t \right) dt = \\ &= \sum_{k=1}^{|I \times J \times 2|} \left(\frac{d_{\sigma(k)} y_{\sigma(k)}}{\tilde{V}_{p(k)}} \cdot \frac{\tilde{v}_{\sigma(k)}}{N_{p(k)} M_{p(k)}} \left(\max_{(i,j,p) \in A_{\sigma(k)}} \{\pi_{ijp}\} - \max_{(i,j,p) \in A_{\sigma(k-1)}} \{\pi_{ijp}\} \right) \right). \end{aligned} \tag{4}$$

The third objective function (4) seeks to minimize the *monotone expectation of total fuzzy time for evacuating victims* based on the distance between affected area to 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 (4) dt is the Riemann integral's differential, Pos is a possibility distribution of impossibility degrees of vehicle movement between affected areas and shelters $-\{\pi_{ijp}, i \in I,\ j \in J;\ p \in \{h, g\}\}$, $\frac{d_{\sigma(k)} y_{\sigma(k)}}{\tilde{V}_{p(k)}} \cdot \frac{\tilde{v}_{\sigma(k)}}{N_{p(k)} M_{p(k)}}$ is a k-th largest of values $\left\{ \frac{d_{ij} y_{ijp}}{\tilde{V}_p} \cdot \frac{\tilde{v}_i}{N_p M_p}, i \in I,\ j \in J;\ p \in \{h, g\} \right\}$, $A_{\sigma(k)} = \left\{ (i, j, p) : \frac{d_{ij} y_{ijp}}{\tilde{V}_p} \cdot \frac{\tilde{v}_i}{N_p M_p} \geq \frac{d_{\sigma(k)} y_{\sigma(k)}}{\tilde{V}_{p(k)}} \cdot \frac{\tilde{v}_{\sigma(k)}}{N_{p(k)} M_{p(k)}} \right\}$, $A_{\sigma(0)} = \varnothing$. The value of this objective function coincides with the Choquet finite integral [11] with respect to the possibility measure Pos.

Objective 4.

$$Min\ Z_3 = \sum_{j \in J} x_j \ . \tag{5}$$

The fourth objective function (5) aims to minimize the *number of open shelters required to thoroughly serve the victims*.

Subject to

$$\sum_{j \in J} \sum_{p \in \{h,g\}} y_{ijp} = 1, \quad \forall i \in I \ . \tag{6}$$

Constraint (6) 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).

$$y_{ijp} \le x_j, \ \ \forall i \in I, \ j \in J; \ p \in \{h,g\} \ \cdot \tag{7}$$

Constraint (7) stipulates that affected area i must be assigned to only open shelters j.

$$d_{ij} y_{ijp} \ge \tilde{s}_{ij}, \ \ \forall i \in I, \ j \in J; \ p \in \{h,g\} \ . \tag{8}$$

Constraint (8) requires that the distance between affected area i to assigned shelter j must be farther than the minimum acceptable distance $\tilde{s}_{ij}$ (fuzzy constraint).

$$\frac{d_{ij} y_{ijp}}{\tilde{V}_p} \cdot \frac{\tilde{v}_i}{N_p M_p} \le \tilde{W}_p, \ \ \forall i \in I, \ j \in J; \ p \in \{h,g\} \ . \tag{9}$$

Constraint (9) limits the duration for evacuating victims from an affected area i to shelter j to no longer than the maximum allowed time for evacuating $\tilde{W}$ (fuzzy constraint).

$$\sum_{i \in I} z_{ij} \le c_j x_j, \ \ \forall j \in J \ . \tag{10}$$

Constraint (10) restricts the number of assigned victims to within the capacity of selected shelter j.

$$\sum_{j \in J} z_{ij} = E^{Pos}(\tilde{v}_i), \ \ \forall i \in I \ . \tag{11}$$

Constraint (11) ensures the number of assigned victims is equal to the expectation number of victims in each affected area i ($E^{Pos}(\tilde{v}_i)$ denotes a possibilistic expected value [10] of a fuzzy number $\tilde{v}_i$).

$$x_j \in \{0,1\}, \ \ \forall j \in J \ . \tag{12}$$

Constraint (12) is a binary variable: x_j is 1 if candidate shelter is selected to open; otherwise, it is 0.

$$x_{ij} \in \{0,1\}, \ \ \forall i \in I, \ j \in J \ . \tag{13}$$

Constraint (13) is a binary variable: x_{ij} is 1 if affected area i is allocated to candidate shelter j; otherwise, it is 0.

FMOESLVEP can be modeled on the possibilistic “Chance-Constrained” multi-objective programming problem. For example, the objective function 3 (formula 4) can be replaced by ($4'$) $\min Z_3 = \bar{Z}$ with addition of a possibilistic constraint:

$$Max\left(\pi_{ijp} : \frac{d_{ij} y_{ijp}}{\tilde{V}_p} \cdot \frac{\tilde{v}_i}{N_p M_p} \le \bar{Z} \right) \le \beta,$$

where $\overline{Z}$ is the estimated admissible time for evacuating victims from the disaster zone and $\beta < 1$ is some minimal possibilistic level.

The presented model has been given with assumption that parameters are certain or evaluated by experts. In the real world, there is uncertainty in many of these parameters. To get closer to the real conditions, in the next section, the model will be developed in uncertain conditions. A relatively simplified model has been discussed here in order to present the task well. Clearly, the work realization execution tasks will build on deeply detailed models close to the real-life situations. To develop the work tasks, the model's linearization and robust optimization approaches will be used in our future investigations.

Conclusions

We assume fuzziness in the constructed FMOESLVEP models, because there is insufficient amount of objective information on disaster zone data. In evaluating the required parameters in the model, we use the knowledge and experience of experts (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 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 of monotone expectation of total time for victims' evacuation, and (4) minimizing the number of open shelters. Objective functions (1) and (3) are novel and their construction and study issues are one of the important tasks of the project. The models take into account the interactions between decision making attributes by aggregating the extended Choquet integral. The realization scheme of the solution for the FMOESLVEP models is given.

The input to the mathematical model of the system will be objective data, as well as expert evaluations. The output of the system will solve the FMOESLVEP for disaster zones. Based on the obtained results, the Intelligent Support System for the FMOEVRP in disaster zones will be developed in our future research. Programming, testing and implementation will be made on the example of an experimental disaster region of Georgia, which emergency will be generated by the simulation modeling. The created software product will be transferred to the Emergency Management Agency of Georgia.

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ინფორმატიკა

კატასტროფის რეგიონში თავშესაფრების ადგილმდებარეობის შერჩევისა და დაზარალებულთა ევაკუაციის ჰუმანიტარული დახმარების ლოგისტიკის ფაზი-დაგეგმვის მოდელი

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**ივანე ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტი, კომპიუტერულ მეცნიერებათა ფაკულტეტი, თბილისი, საქართველო*
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ბოლო წლებში მნიშვნელოვნად გაიზარდა ადამიანის სიცოცხლის დანაკარგები და მატერიალური ზარალი, რომელიც გამოწვეულია ბუნებრივი კატასტროფებით, რამაც შეიძლება სერიოზული და ხანგრძლივი ზიანი მიაყენოს ქვეყნებს. როდესაც შეირჩევა თავშესაფრების ადგილმდებარეობის შესაფერისი ადგილები, მათგან უნდა შეირჩეს ადგილების ჯგუფი, რომელიც გარკვეულწილად უკეთ აკმაყოფილებს ისეთ მოთხოვნებს, როგორიცაა: თავშესაფრების შერჩევის სანდოობის ინდექსის მაქსიმიზაცია, ხარჯების მინიმიზაცია, ევაკუაციის დაფარვის მაქსიმალური გაზრდა და ა.შ. ასეთ შემთხვევებში ძალზე მნიშვნელოვანია ინტელექტუალური მხარდაჭერის ტექნოლოგიების გამოყენება საგანგებო სიტუაციებში განთავსება-ტრანსპორტიზაცია-მარშრუტიზაცია სწრაფი და ოპტიმალური მომსახურებისთვის, რათა თავიდან იქნეს აცილებული განმეორებითი ექსტრემალური მოვლენებით გამოწვეული ახალი დანაკარგები. სტიქიით დაზარალებული ტერიტორიებიდან დაზარალებულთა დროული ევაკუაციის უზრუნველყოფა საგანგებო სიტუაციების მართვის სისტემის ერთ-ერთი უმნიშვნელოვანესი ამოცანაა. ჩვენ ვვარაუდობთ არამკაფიობის დაშვებას დაფარვის, ადგილმდებარეობის, ტრანსპორტირებისა და მარშრუტიზაციის პრობლემების მოდელებში, რადგან კატასტროფის ზონის მონაცემებზე ობიექტური ინფორმაცია არასაკმარისია. მოდელში საჭირო პარამეტრების შეფასებისას ვიყენებთ ექსპერტების (მარშრუტის ქსელის დისპეტჩერების და ა.შ.) ცოდნას და გამოცდილებას. ზემოაღნიშნული საკითხების გათვალისწინებით, სტიქიით დაზარალებული ზონებისთვის ჩვენ განვიხილავთ ფაზი-მრავალფუნქციური გადაუდებელი თავშესაფრების განთავსებისა და დაზარალებულთა ევაკუაციის ამოცანას (FMOESLVEP). მოდელის მიზნები მოიცავს: (1) გახსნილი თავშესაფრების მთლიანი შერჩევის სანდოობის ინდექსის მაქსიმიზაციას, (2) მთლიანი ხარჯების მინიმიზაციას, მათ შორის, თავშესაფრების გახსნის ფიქსირებული ხარჯების, მსხვერპლთა ტრანსპორტირების ხარჯებისა და მომსახურების ხარჯების მინიმიზაციას, (3) დაზარალებულთა ევაკუაციის მთლიანი დროის მონოტონური მოლოდინის მინიმუმამდე შემცირებასა და (4) გახსნილი თავშესაფრების რაოდენობის შემცირებას. მიზნის ფუნქციები (1) და (3) ახალია და მათი კონსტრუქციისა და შესწავლის საკითხები

სტატიის ერთ-ერთი მნიშვნელოვანი ამოცანაა. FMOESLVEP მოდელები შემუშავებულია სხვადასხვა შემავალი ფაზი-ინფორმაციისთვის. მოდელები ითვალისწინებს გადაწყვეტილების მიღების ატრიბუტებს შორის ურთიერთქმედებას გავრცობილი შოკეს ინტეგრალით აგრეგაციის გზით. მოცემულია FMOESLVEP მოდელების გადაწყვეტის რეალიზაციის სქემა.

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