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ROUTE PLANNING FOR HAZARDOUS MATERIALS TRANSPORTATION: MULTI-CRITERIA DECISION-MAKING APPROACH

Mohammad Noureddine [1*] and Milos Ristic [2]

[1] Faculty of science and technology, University of Djelfa, Djelfa, Algeria
[2] University of defence in Belgrade, Department of logistics, Belgrade, Serbia

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Abstract: *Transport of hazardous material (THM) represents a complex area involving a large number of participants. The imperative of THM is minimization of risks in the entire process of transportation from the aspect of everyone involved in it, which is not an easy task at all. To achieve this, it is necessary in its early phase to carry out adequate evaluation and selection of an optimal transport route. In this paper, optimal route criteria for THM are selected using a new approach in the field of multi-criteria decision-making. Weight coefficients of these criteria were determined by applying the Full Consistency Method (FUCOM). Evaluation and selection of hazardous material routes is determined by applying the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) and the MABAC (Multi-attributive Border Approximation Area Comparison) methods. In order to establish the stability of models and validate the results obtained from the FUCOM-TOPSIS-MABAC model, a sensitivity analysis (of ten different scenarios) was performed. The sensitivity analysis implied changes of the weight coefficients criteria with respect to their original value. The proposed route model was tested on the real example of the transport Eurodiesel in Serbia.*

Key words: *Hazardous Materials Routing, FUCOM, TOPSIS, MABAC, Multi-criteria Decision-making.*

1. Introduction

The rapid development of industry, based on the development of techniques and technology increased the usage of substances, materials, elements, which are hazardous to human health and safety as well as environment safety. Modern industry,

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* Corresponding author.
E-mail addresses: mohammad.noureddine@udd.edu (M. Noureddine) and milos.ristic@mod.gov.rs (M. Ristic)

especially the one of chemical character, also contributes to the faster development of new materials whose usage can cause huge destruction and damage.

The issues of storage and transport, shipping (loading), discharging (unloading) or reloading, or the issues of the activities related to process of transport and storage of these substances are very sensitive. Especially during these activities the risk of unwanted consequences is significantly high and each accident can turn into catastrophe.

From the aspect of transport, realization of each transport process of hazardous material implies a certain risk of an unwanted(accident) event, caused by scattering (effusion, shedding, etc.) of burden, with the consequences related to the nature of the hazardous material that is being transported. By mentioning all of these risks, the transport safety is a very important and responsible task. In the case of an accident, the consequences can be very large and can cause damage to people and their environment, namely, death, diseases of human beings, plant and animals, pollution of environment, destruction of natural and national resources, damage of industrial buildings, traffic communications and their respective facilities.

Potential danger, on one hand, and the need for transport of hazardous materials, on the other hand, both lead to the necessity of setting specific requirements related to risk reduction and attempts to increase the safety in the transport of hazardous materials. With the growth of ecological consciousness, there is also a growing demand for reduction of transport risks, but also in handling, in general, hazardous materials. Because of these reasons, numerous countries, institutions and organizations have different regulations and other regulatory measures in order to manage the safety of these transport processes.

To keep the hazardous materials transport process safe, it is necessary to manage the risk. Risk management represents a very complex process, consisting of several steps and elements. Certainly one of the most important steps in this process is the selection of routes for the movement of vehicles that carry hazardous load (material). The problem of routing in the transport of hazardous materials, as a problem of multi-criteria factors, became popular in the 90s of the last century. Approaches to solving this problem are numerous and depend on many factors, such as the methods used to identify risks, the criteria that are considered, the ways in which these criteria are valued, etc. This is necessary because the requirements for transporting hazardous materials are very complicated; this implies a very difficult task for the managers assigned to properly evaluate potential hazardous materials transport routes (THM) that will enable efficient and safe transportation. In order to minimize THM risks, efficient management strategy has become a key risk minimization component (Pamucar et al., 2016).

When considering the efficiency of the entire THM it is impossible not to notice that it largely depends on adequate route selection because this process represents one of the most important factors that directly affect the overall risk and safety of transport. Only by properly evaluating and selecting routes this logistical subsystem can efficiently perform tasks related to end-user supply. In this paper, the choice of optimum route for THM was performed using linear programming and multi-criteria evaluation of the THM route. The weight coefficients of the criteria are determined by linear programming. Evaluation and selection of route for THM was performed using TOPSIS and MABAC methods. These multi-criteria techniques were chosen because the TOPSIS method is one of the most commonly used multi-criteria techniques (Song et al, 2014), while the MABAC method is one of the newest methods in this area that has found a wide and efficient application in many areas (Yu et al, 2016; Xue et al, 2016; Peng and Dai, 2016; Peng and Yang, 2016; Roy et al, 2016; Gigovic et al, 2017; Pamucar et al., 2018).

This paper has more goals. The first objective is to improve the methodology for route optimization for the THM. The second goal of this paper is the popularization of the operational research, especially linear programming and multi-criteria techniques, through their application for decision-making in a real business and business system. The third goal of the paper is a proposal of a model that comprehensively addresses the problem of hazmat rutting with respect to both cost aspects and different aspects of risk, as well as a number of uncertainties in the decision-making process. By proposing the new model of the LP-TOPSIS-MABAC hybrid model, it is trying to show that academic research models can be more practical and useful for actually planning the routes.

The paper is structurally divided into six sections. In the next section, an overview of the literature with an accent on the criteria for selecting the optimal route for THM is given. In addition, the methods used to optimize the THM process have been presented. In the third section, the FUCOM-TOPSIS-MABAC hybrid model algorithms are presented: (1) FUCOM - for defining weight coefficient criteria, (2) TOPSIS model - for THM route evaluation and (3) MABAC model for THM route evaluation. The fourth section is the application of the above mentioned techniques of operational research to a real problem. In the fifth section, a sensitivity analysis was performed defining different sets with different criteria values based on which the stability of the proposed model was verified. Section six is conclusion with the guidelines for future research.

2. Literature review

Multi-criteria decision-making is widely applied in all areas, and when it comes to transport, more precisely the sub-system of transport carried out by THM is often used to select transport routes (Pamucar et al., 2016). For the purposes of this paper, the author's works have been analyzed to deal with the problem of choosing the optimal route for the THM and thus the choice of criterion of choice. Among them, it was noted that the sources the authors rely on are often similar, so most of the criteria are repeated in the works of different authors. Consequently, in this paper are presented and analyzed the characteristic works, which are set out according to the methodology and criteria applied.

Wijerante et al., (1993) have developed a method for determining undetermined routes in the network when there are multiple, uncertain measures based on which route estimates are made and applied to a transport hazard example in the territory of New York State (United States). In order to evaluate the route options and choose optimal, they based their analysis on three criteria: time of transport, incidence of traffic accidents resulting from hazardous substances and operating costs.

The issue of risk modeling in the transport of hazardous materials and the question of the importance of the way of evaluating this risk was addressed by Erkut and Verter (1998). They presented an overview of the models and methods most commonly used in theory and practice, and their empirical analysis was conducted on the American road network. They concluded that choosing the optimum route for THM depends on the way of risk assessment, i.e. they have shown the impact of different risk assessment models on selecting the optimal route for THM.

To consider the THM impact on the environment was of great importance when choosing the route, as shown in Monprapussornte al., (2009). The authors also pointed out to the possibility of applying a decision support system, such as the Multi Criteria Decision Analysis (MCDA) and the Geographic Information System (GIS), which make easier the selection of routes while planning THM, while respecting the environmental criteria. In that study Monprapussornte al., (2009) the environmental factor has been identified as one of the key factors in addition to those that are economically linked to safety and the ability to react in emergency situations.

To establish a network of roads for THM, Law and Rocchi (2008) conducted research in Canada. The goal of this study was to establish a network of THM routes in Canada. The authors have analyzed and used current methodological approaches (MCDM, routing algorithms etc.) that used different route agencies when determining routes in some other cities and regions. Law and Rocchi (2008) have proposed criteria for route evaluation as well as methodology for choosing the optimal route for THM based on the MCDM approach.

Huang et al., (2004) and Huang and Fery (2005) dealt with the choice of the THM route in Singapore as the third oil refinery in the world. Given the increased number of trucks carrying hazardous goods in this city, the authors have pointed out the need to improve the tracking and safety of trucks driving on the city and suburban road network at THM. To select the optimal directions for THM authors proposed risk mapping and GIS application in combination with genetic algorithms in this study.

Samuel (2007) presented a time study, which covers the time period from 1995 to 2007, in which he analyzed 1850 incidents in transport of flammable-liquid substances. Focus studies include shipments of hazardous cargo from five US states (California, Illinois, Iowa, New Jersey, and Texas), which were selected due to their size and geographic location differences. The main objective of this study was to analyze the frequency of incidents during THM and as a result of the analysis, thirteen criteria for route selection were set out.

The importance of safety when transporting hazardous materials was pointed out as well by Dilgir, et al., (2005). They consider that THM that run on roads that pass through larger cities are not only a challenge for transporters, but also for city planners and services designed to respond to emergency situations. Dilgir, et al., (2005) point out that road safety is a key criterion for efficient route selection for THM and suggest the use of MCDM techniques to solve this problem. Sattayaprasert et al., (2008) have proposed multi-criteria models to form an efficient logistic network, with particular reference to the risk inherent in THM. Using the Analytic Hierarchy Process (AHP) Sattayaprasert et al., (2008) have observed a case of study related to petrol logistics as one of the most frequently transported hazardous cargoes in Thailand. The AHP structure of the criteria which they have established is based on the evaluation and opinions of the expert group and the local community.

As most of the authors of the previously analyzed papers pointed to the consequences of cargo carrying hazardous cargo, Oluwoye (2007) deals with the effects and risks of the environment if accidents occur during this type of transport. Oluwoye(2007) states that if an economical and efficient risk management strategy is to be achieved, optimization must be carried out to minimize costs and impact on the environment. Milovanovic (2012) also deals with the topic of selecting an adequate route from the aspect of risk management and provides an overview of the risk management process in hazardous materials transport, i.e. the phases of the risk management process, as well as a detailed description of each phase. In order to determine the level of risk Milovanovic (2012) defines two types of parameters. The first group of parameters affects the probability of an incident while the other group of parameters affects the consequences of an incident.

Li and Leung (2011) also viewed a multi-objective optimization problem as the problem of selecting the transport route hazmat on the urban network. They proposed a compromise programming approach to modify the Dijkstring's algorithm while for the attribution of weight coefficient they used the Analytic Hierarchy Process, considering that they will minimize human subjectivity in decision-making.

From the previous literature analysis, it can be said that the multi-criteria analysis is used as a tool for achieving the best possible trade – off among different objectives (Li & Leung, 2011). It should be borne in mind that the optimality of multi-objective solutions in the hazmat routing domain implies the so-called "Pareto-optimality”. More about Pareto concept can be seen in (Das et al., 2012). In the application of the multi-criteria analysis method for selecting the hazmat transport route, hybrid models are often proposed in which these methods combine with the classical shortest path algorithms or Geographic information systems - GIS (AHP method and Dijkstra's algorithm) (Verma, 2011; Li & Leung, 2011), AHP method and GIS (Long &Liew, 2003; Huang, 2006; Sattayaprasert et al., 2008). The application of other multi-criteria analysis methods, such as PROMETHEE and TOPSIS, in vehicle routing problems, can be seen in (Bandyopadhyay& Bhattacharya, 2013; Jia et al., 2013; Talarico, 2015).

The literature review shows that in the literature there are known crisp multi-criteria algorithms based on the most common application of GIS models with AHP, TOPSIS and PROMETHEE algorithms. Considering that the TOPSIS method falls into the methods found to be the widest application in solving multi-criteria models (Song et al., 2014; Stevic et al., 2016; Zhang et al., 2017) it is justified to further develop the TOPSIS method algorithm through the application of other approaches. In order to achieve greater objectivity in decision-making over the last several years, numerous multi-criteria models have been developed among which the swords and MABAC methods (Pamucar&Cirovic, 2015).The authors agreed to apply the MABAC method due to many advantages it recommends: (1) the mathematical framework of the method remains the same regardless of the number of alternatives and criteria; (2) the possibility of applying in the case of a number of alternatives and criteria; (3) a clearly defined ranking of alternatives is expressed in numerical value, which allows a better understanding of the results; (4) it is applicable to the qualitative and quantitative criterion type and (5) it provides stable solutions regardless of the change in the scale of qualitative criteria and the change in the formulation of the quantitative criteria (Pamucar&Cirovic, 2015). The original model based on the Linear Programming (LP) was suggested for determining weight criteria. The main advantages of the LP models are as follows: (1) Weight coefficients obtained with the LP model represent fair values since the input data is obtained with a small number comparing to the real criteria; (2) The mathematical framework of the model remains the same regardless of the number of criteria; (3) The LP model provides stable solutions regardless of the type of scale used to represent the expert preferences. Taking into account all the advantages of the LP, TOPSIS and MABAC models in the decision-making process, the authors have decided in this paper to present the hybrid LP-TOPSIS-MABAC model for selecting the optimal route for THM.

3. Multi-criteria model for choosing the optimal route for THM

The model for optimal route selection for THM is realized through two phases. In the first phase of the hybrid FUCOM-TOPSIS-MABAC model using the linear programming model, the weighting coefficients of the evaluation criterion are calculated. In the second phase of the FUCOM -TOPSIS-MABAC model, a THM route evaluation is performed using TOPSIS and MABAC models.

3.1. Determining weight coefficient criteria - FUCOM model

FUCOM (Pamucar et al., 2018) is a new MCDM method for determination of criteria weights. In the following section, FUCOM algorithm is shown, which implies the following steps:

Step 1. Determining the set of evaluation criteria. This starts from the assumption that the process of decision-making involves *m* experts. In this step, experts consider the set of evaluation criteria and select the final set of criteria $C=\left\{c_1,c_2,\dots c_n\right\}$, where *n* represents the total number of criteria.

Step 2. The second step is to rank the criteria according to their significance. The criterion we expect to have the highest weight coefficient gets the first rank, while the least important criterion gets the last rank. The remaining criteria get the rankings between the most important and the least important criterion. The ranks of the criteria are presented by the experts in descending order in accordance with the expected values of weight coefficients $C_{j(1)}^{(e)} > C_{j(2)}^{(e)} > \dots > C_{j(k)}^{(e)}$, where *k* represents the rank of the observed criterion, whereas *e* represents the mark of expert $1 \le e \le m$.

Step 3. The third step is to compare the ranked criteria together and compare the significance of the evaluation criterion. Comparative significance of the criterion of evaluation is an advantage that has a higher ranking criterion in relation to the lower rank criterion.

The final values of the weight coefficients should meet the following two conditions:

(1) The relation of the weight coefficients should be the same as the comparative importance between observed criteria ($\varphi_{k/(k+1)}^{(e)}$), which is defined in *Step 2*, meeting the condition:

$$\frac{w_k^{(e)}}{w_{k+1}^{(e)}}=\varphi_{k/(k+1)}^{(e)} \tag{1}$$

(2) Apart from the condition (1), the final values of the weight coefficients should meet the condition of mathematical transitivity, so that $\varphi_{k/(k+1)}^{(e)} \otimes \varphi_{(k+1)/(k+2)}^{(e)} = \varphi_{k/(k+2)}^{(e)}$. Taking into consideration the fact that $\varphi_{k/(k+1)}^{(e)}=\frac{w_k^{(e)}}{w_{k+1}^{(e)}}$ and $\varphi_{(k+1)/(k+2)}^{(e)}=\frac{w_{k+1}^{(e)}}{w_{k+2}^{(e)}}$, $\frac{w_k^{(e)}}{w_{k+1}^{(e)}} \otimes \frac{w_{k+1}^{(e)}}{w_{k+2}^{(e)}} = \frac{w_k^{(e)}}{w_{k+2}^{(e)}}$ is obtained. In that manner, the second condition that the final values of the weight coefficients of the evaluation criteria should meet is:

$$\frac{w_k^{(e)}}{w_{k+2}^{(e)}}=\varphi_{k/(k+1)}^{(e)} \otimes \varphi_{(k+1)/(k+2)}^{(e)} \tag{2}$$

Step 4. Solving the optimization model (3) the final values of the weighting coefficients of the evaluation criteria are calculated $\left(w_1, w_2, ..., w_n\right)^T$.The minimum deviation from the maximum consistency (DFC) of the comparison (χ) is only met if transitivity is fully complied with, when the conditions are met, where $\frac{w_k^{(e)}}{w_{k+1}^{(e)}} - \varphi_{k/(k+1)}^{(e)} = 0$ and $\frac{w_k^{(e)}}{w_{k+2}^{(e)}} - \varphi_{k/(k+1)}^{(e)} \otimes \varphi_{(k+1)/(k+2)}^{(e)} = 0$. Then, the condition of the maximum consistency is met, respectively, for the obtained values of the weight coefficients, the deviation from the maximum consistency being $\chi = 0$. In order to meet the mentioned conditions, it is necessary to determine the values of the weight coefficients of evaluation criteria $\left(w_1^{(e)}, w_2^{(e)}, ..., w_n^{(e)}\right)^T$ meeting the condition, where $\left|\frac{w_k^{(e)}}{w_{k+1}^{(e)}} - \varphi_{k/(k+1)}^{(e)}\right| \le \chi$ and $\left|\frac{w_k^{(e)}}{w_{k+2}^{(e)}} - \varphi_{k/(k+1)}^{(e)} \otimes \varphi_{(k+1)/(k+2)}^{(e)}\right| \le \chi$, while minimizing the values, thus meeting the condition of the maximum consistency.

Based on the mentioned assumptions, the final model for determining the values of the weight coefficients of the evaluation criteria can be defined as follows:

$$\begin{aligned}
&\min \chi \\
&s.t. \\
&\left|\frac{w_k^{(e)}}{w_{k+1}^{(e)}} - \varphi_{k/(k+1)}^{(e)}\right| \le \chi,\ \forall j \\
&\left|\frac{w_k^{(e)}}{w_{k+2}^{(e)}} - \varphi_{k/(k+1)}^{(e)} \otimes \varphi_{(k+1)/(k+2)}^{(e)}\right| \le \chi,\ \forall j \\
&\sum_{j=1}^{n} w_j^{(e)} = 1,\ \forall j \\
&w_j^{(e)} \ge 0,\ \forall j
\end{aligned} \tag{3}$$

By solving Model (3), the final values of the evaluation criteria $\left(w_1^{(e)}, w_2^{(e)}, ..., w_n^{(e)}\right)^T$ and the DFC ($\chi^{(e)}$) for every expert are obtained.

3.2. TOPSIS method

The TOPSIS method implies ranking alternatives with respect to the multiple criteria based on distance comparison with an ideal solution and a negative ideal solution (Chang et al., 2010). The ideal solution minimizes the cost-type criteria and maximizes the criteria of the benefit type, while the negative ideal solution works the other way around. A simple example is an effort to make (identify) decisions in business decision-making maximizing profit and minimizing the risk. The optimal alternative is the one that is geometrically closest to the ideal solution, that is, the farthest from the ideal negative solution (Srdjevic et al., 2002). The ranking of alternatives is based on a "relative connection with an ideal solution", thus avoiding the situation that the alternative simultaneously has the same resemblance to the ideal and the negative ideal solution. The ideal solution is defined by using the best value rating alternatives for each individual criterion. A negative ideal solution represents the worst value rating alternative. TOPSIS method consists of 6 steps that are shown in the following section.

Step 1. Normalization of decision matrix values. For the majority of multi-criteria decision-making, the first step is the normalization of the elements of the decision matrix to obtain a matrix in which all elements are non–dimensional in size. The TOPSIS method applies vector normalization that is represented by expressions (4) and (5):

$$x_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{n} r_{ij}^{2}}} \text{ ,for “benefit“ criteria type,} \tag{4}$$

$$x_{ij} = 1 - \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r_{ij}^{2}}} \text{, fort ”cost” criteria type} \tag{5}$$

After normalization, we get a matrix X in which all the elements are standardized and are in the interval [0, 1].

$$X = \begin{array}{c} A_1 \\ A_2 \\ \cdot \\ A_3 \end{array} \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \dots & \dots & & \dots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix} \tag{6}$$

Step 2. Multiplication of normalized matrix values X with the weight coefficient criteria

$$v_{ij} = x_{ij} \cdot w_j ; \quad j = 1, 2, \dots, m \tag{7}$$

Using the relation (7) we get elements of weight normalized matrix $V = (v_{ij})$, where everyone is v_{ij} a product of normalized alternate performance and an appropriate weighting coefficient of the criterion.

$$V = \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_3 \end{array} \begin{bmatrix} v_{11} & v_{12} & \dots & v_{1m} \\ v_{21} & v_{22} & \dots & v_{2m} \\ \dots & \dots & & \dots \\ v_{n1} & v_{n2} & \dots & v_{nm} \end{bmatrix} = \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_3 \end{array} \begin{bmatrix} w_1 \cdot x_{11} & w_2 \cdot x_{12} & \dots & w_m \cdot x_{1m} \\ w_1 \cdot x_{21} & w_2 \cdot x_{22} & \dots & w_m \cdot x_{2m} \\ \dots & \dots & \dots \quad \dots & \dots \\ w_1 \cdot x_{n1} & w_2 \cdot x_{n2} & \dots & w_m \cdot x_{nm} \end{bmatrix} \tag{8}$$

Step 3. Determining ideal solutions. Ideal solution A^* and negative ideal solution A^- are determined by the relation:

$$A^* = \left\{ (\max v_{ij} \mid j \in G), (\min v_{ij}, j \in G), i = 1,..,n \right\} = \left\{ v_1^*, v_2^*, \dots, v_m^* \right\} \tag{9}$$

$$A^- = \left\{ (\min v_{ij} \mid j \in G), (\max v_{ij}, j \in G^{'}), i = 1,..,n \right\} = \left\{ v_1^-, v_2^-, \dots, v_m^- \right\} \tag{10}$$

where :

$G = \left\{ j = 1, 2, \dots, m \mid \right\}$, for ”benefit”criteria type

$G^{'} = \left\{ j = 1, 2, \dots, m \mid \right\}$,for ”cost” criteria type

Step 4. Determining the distance of alternatives to ideal solutions. In this step, using the following links:

$$S_i^* = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^*)^2}\ , \quad i = 1,\dots,n \tag{11}$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^-)^2}, \quad i = 1,\dots,n \tag{12}$$

calculated *n* dimensional Euclidean distances of all the alternatives of an ideal and ideal negative solution.

Step 5. Determining the relative proximity of an alternative to an ideal solution. For each alternative, a relative interval is determined

$$Q_i^* = \frac{S_i^-}{S_i^* + S_i^-}, i = 1,\dots,n \tag{13}$$

where $0 \le Q_i^* \le 1$. Alternative A_i is closer to ideal solution if Q_i^* is close to 1, or, which is the same, if S_i^* is closer to 0.

Step 6. Ranking alternatives. Alternatives are ranked by decreasing values Q_i^*. The best alternative is the one whose value Q_i^* is the highest and *vice versa*.

3.3. MABAC method

The basic function of the MABAC method is to define the distance of the criterion function of each observed alternative from the boundary approximating area. In the following section, the procedure for conducting the MABAC method consists of five steps.

Step 1. Normalization of element from initial matrix (X):

$$N = \begin{array}{c} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} t_{11} & t_{12} & \dots & t_{1n} \\ t_{21} & t_{22} & & t_{2n} \\ \dots & \dots & \dots & \dots \\ t_{m1} & t_{m2} & \dots & t_{mn} \end{bmatrix} \end{array} \tag{14}$$

Elements of normalized matrix (N) are determined using the expression:

(a) for the "benefit" type criteria (a higher value criterion is more desirable))

$$t_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \tag{15}$$

(b) for “cost “ type criteria (a lower value criterion is more desirable)

$$t_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \tag{16}$$

where x_{ij}, x_i^+ and x_i^- represent the elements of initial decision matrix (X), whereby x_i^+ and x_i^- defined as:

$x_i^+ = \max\left(x_1, x_2, \dots, x_m\right)$ and represents the maximum value of the observed criterion by alternatives and

$x_i^- = \min(x_1, x_2, ..., x_m)$ and represents the minimum values of the observed criterion by alternatives.

Step 2. Calculation of weighted matrix elements (V).Calculation of weighted matrix elements (V) are calculated based on expression (17):

$$v_{ij} = w_i \cdot t_{ij} + w_i \tag{17}$$

where t_{ij} represent elements of a normalized matrix (N), w_i represents the weighting criterion coefficients. Using expression (17) we get weighted matrix V :

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & & v_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} = \begin{bmatrix} w_1 \cdot t_{11} + w_1 & w_2 \cdot t_{12} + w_2 & \cdots & w_n \cdot t_{1n} + w_n \\ w_1 \cdot t_{21} + w_1 & w_2 \cdot t_{22} + w_2 & \cdots & w_n \cdot t_{2n} + w_n \\ \cdots & \cdots & \cdots & \cdots \\ w_1 \cdot t_{m1} + w_1 & w_2 \cdot t_{m2} + w_2 & \cdots & w_n \cdot t_{mn} + w_n \end{bmatrix}$$

where n represents the total number of criteria, m represents the total number of alternatives.

Step 3. Determination of matrix of border approximate domains (G). The Boundary Approximate Area (GAO) is determined according to expression (18):

$$g_i = \left(\prod_{j=1}^{m} v_{ij} \right)^{1/m} \tag{18}$$

where v_{ij} represent elements of a heavy matrix (V), m represents the total number of alternatives.

After calculating value g_i according to the criteria, a matrix of border approximating areas is formed G (19) formats $n\ x\ 1$ (n represents the total number of criteria by which a choice of alternatives is offered):

$$\begin{array}{cc} & \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ G = & \begin{bmatrix} g_1 & g_2 & \cdots & g_n \end{bmatrix} \end{array} \tag{19}$$

Step 4. Calculation of the matrix elements of the distance of alternatives from boundary approximating area (Q):

$$Q = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & & q_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \tag{20}$$

Alternative distance from border approximate area (q_{ij}) is defined as the difference between the elements of a heavy matrix (V) and values of border approximate areas (G):

$$Q = V - G = \begin{bmatrix} v_{11} - g_1 & v_{12} - g_2 & \cdots & v_{1n} - g_n \\ v_{21} - g_1 & v_{22} - g_2 & \cdots & v_{2n} - g_n \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} - g_1 & v_{m2} - g_2 & \cdots & v_{mn} - g_n \end{bmatrix} = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & & q_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \tag{21}$$

where g_i represents a border approximate area for criterion C_i, v_{ij} represents the elements of a heavy matrix (V), n represents the number of criteria, m represents the number of alternatives.

Alternative A_i may belong to borderline approximate area (G), upper approximate area (G^+) or lower approximate area (G^-), regarding $A_i \in \left\{ G \vee G^+ \vee G^- \right\}$. Upper approximate area (G^+) represents the area in which the ideal alternative is (A^+), lower approximate area (G^-) represents the area where the anti-ideal alternative is(A^-).

Step 5. Ranking alternatives. Calculation of criterion values by alternatives (22) is obtained as a sum of limiting alternatives to border-approximating areas (q_i). Summing up matrix elements Q we get the final values of the criterion functional alternatives in a row:

$$S_i = \sum_{j=1}^{n} q_{ij},\ j = 1, 2, \dots, n,\ i = 1, 2, \dots, m \tag{22}$$

4. Selection of THM routes using the FUCOM-TOPSIS-MABAC model

The FUCOM-TOPSIS-MABAC model was tested on the example of choosing the optimal route for THM (Eurodiesel) in the Petroleum Industry of Serbia. THM is performed on the village Leskovac - Šabac. During THM, the vehicle moves from Kragujevac and has a zero drive to the warehouse in the village of Leskovac. Transport can be carried out over four routes that represent alternatives:

A1 - route: Kragujevac – Knic - v. Leskovac – Knic – Preljina – Ljig – Mionica – Valjevo – Koceljeva – Vladimirci – Šabac

A2 - route: Kragujevac – Knic - v. Leskovac – Knic – Preljina – Ljig – Lajkovac – Ub – Šabac

A3 - route: Kragujevac – Knic – v. Leskovac – Knic – Kragujevac – Topola – Mladenovac – Mali Pozarevac – Beograd – Dobanovci – Šimanovci – Šabac

A4 -route: Kragujevac – Knic – v. Leskovac – Knic – Kragujevac – Batocina – Beograd - Dobanovci – Šimanovci – Šabac.

The analysis of the literature presented in the second section of the work contains five criteria for the evaluation of the THM route: Number of rail crossings on the route (C1), Existence of traffic jam on the route (C2), Number of traffic accidents in the last ten years (C3), Reaction of rescue services (emergency aid, fire brigade and police) (C4) and Travel Line Length (C5).

The existence of rail crossing of the road route (C1) carrying hazardous goods presents a great danger from the point of view of traffic accidents (incident situations) due to the fact that there is a large stopping distance to braking of locomotives. Trails with a greater number of rail crossings have a greater degree of risk than those with fewer or no crossings at all.

Traffic jams (C2) directly affect the probability of incident situations. Increasing the number of vehicles that use a certain part of the route directly affects an increase in probability of incident situations. Since traffic accidents with the involvement of individual vehicles are common, traffic jams appear to be an important factor in determining not only the frequency of traffic accidents but also their weights. The following relationships were used to estimate the probability of occurrence of incident situations depending on traffic jam:

- the ratio of traffic speed and traffic capacity is less than 0.5,
- traffic flow velocity and traffic capacity between 0,5 and 0,7 and
- traffic speed ratio and road capacity greater than 0.7.

In order to estimate the probability of occurrence of an incident situation, depending on the number of traffic accidents (C3) on a particular section, the following scale was used within the route:

- 1 to 2 traffic accidents per kilometer per year,
- from 2 to 7 traffic accidents per kilometer per year and
- from 7 to 15 traffic accidents per kilometer per year.

Emergency Response Service (C4) represents the time for which city services (fire services, emergency services and police) react in the case of an accident. It is very important to determine the number of properly trained and well-prepared fire brigades and ambulance services as soon as possible from the base to any point along the route. This determines the effects of these services on softening the consequences of an accident involving the participation of vehicles transporting hazardous materials. On the scale from 1 to 9, values are defined that indicate the response time. Number one represents a small response time, and the number nine means quite a long response time on a particular route.

The minimum distance (C5) between the start and end point of the THM on the route is determined on the basis of available satellite images of the traffic routes. Only first and second line roads were considered.

This research study involved six road safety experts with a minimum of 10 years of experience in managing the transport of hazardous materials. In the first phase of the FUCOM-TOPSIS-MABAC model, the weighting coefficients of the evaluation criteria are calculated using linear programming.

4.1. FUCOM: Defining the weight of the criteria

Experiment surveys obtained the ranking criteria and significance of the criteria that was further used in the LP model. Table 1 shows the results of surveyed experts.

Table 1. Ranking of criteria and determination of significance

Experts	Rank/significance				
E_1	C2	C4	C1	C3	C5
	1	2	2.8	3	3.5
E_2	C3	C2	C5	C4	C1
	1	1.3	1.7	1.5	3
E_3	C4	C5	C1	C2	C3
	1	1.34	1	1.6	1.45
E_4	C5	C4	C2	C1	C3
	1	1.28	1.35	1.62	1.07
E_5	C5	C4	C2	C3	C1
	1	1.2	1.3	1.5	1.6
E_6	C5	C4	C1	C2	C3
	1	1.2	1.4	1.2	1.3

In the next step, based on the model (3), the weight coefficients of the criteria are estimated. Since the research involved six experts, the FUCOM model, which was solved using the LINGO 17.0 software, was formed from any expert. FUCOM models are shown in the next section.

$$Expert\ 1-\min \chi$$

$$\left\{\begin{array}{l}
\left|\frac{w_2}{w_4}-2\right| \le \chi,\ \left|\frac{w_4}{w_1}-2.8\right| \le \chi,\ \left|\frac{w_1}{w_3}-3\right| \le \chi, \\
\left|\frac{w_3}{w_5}-3.5\right| \le \chi, \left|\frac{w_2}{w_1}-2\right| \le \chi, \left|\frac{w_4}{w_3}-5.6\right| \le \chi, \\
\left|\frac{w_1}{w_5}-10.5\right| \le \chi, \\
\sum_{j=1}^{5} w_j = 1,\ w_j \ge 0, \forall j
\end{array}\right.$$

$$Expert\ 2-\min \chi$$

$$\left\{\begin{array}{l}
\left|\frac{w_3}{w_2}-1.3\right| \le \chi,\ \left|\frac{w_2}{w_5}-1.7\right| \le \chi,\ \left|\frac{w_5}{w_4}-1.5\right| \le \chi, \\
\left|\frac{w_4}{w_1}-3\right| \le \chi, \left|\frac{w_3}{w_5}-2.21\right| \le \chi, \left|\frac{w_2}{w_4}-2.55\right| \le \chi, \\
\left|\frac{w_5}{w_1}-4.5\right| \le \chi, \\
\sum_{j=1}^{5} w_j = 1,\ w_j \ge 0, \forall j
\end{array}\right.$$

$$Expert\ 3-\min \chi$$

$$\left\{\begin{array}{l}
\left|\frac{w_4}{w_5}-1.34\right| \le \chi,\ \left|\frac{w_5}{w_1}-1\right| \le \chi,\ \left|\frac{w_1}{w_2}-1.6\right| \le \chi, \\
\left|\frac{w_2}{w_3}-1.45\right| \le \chi, \left|\frac{w_4}{w_1}-1.34\right| \le \chi, \left|\frac{w_5}{w_2}-1.6\right| \le \chi, \\
\left|\frac{w_1}{w_3}-2.32\right| \le \chi, \\
\sum_{j=1}^{5} w_j = 1,\ w_j \ge 0, \forall j
\end{array}\right.$$

$$Expert\ 4-\min \chi$$

$$\left\{\begin{array}{l}
\left|\frac{w_5}{w_4}-1.28\right| \le \chi,\ \left|\frac{w_4}{w_2}-1.35\right| \le \chi,\ \left|\frac{w_2}{w_1}-1.62\right| \le \chi, \\
\left|\frac{w_1}{w_3}-1.07\right| \le \chi, \left|\frac{w_5}{w_2}-1.73\right| \le \chi, \left|\frac{w_4}{w_1}-2.19\right| \le \chi, \\
\left|\frac{w_2}{w_3}-1.73\right| \le \chi, \\
\sum_{j=1}^{5} w_j = 1,\ w_j \ge 0, \forall j
\end{array}\right.$$

$$Expert\ 5-\min \chi$$

$$\left\{\begin{array}{l}
\left|\frac{w_5}{w_4}-1.2\right| \le \chi,\ \left|\frac{w_4}{w_2}-1.3\right| \le \chi,\ \left|\frac{w_2}{w_3}-1.5\right| \le \chi, \\
\left|\frac{w_3}{w_1}-1.6\right| \le \chi, \left|\frac{w_5}{w_2}-1.56\right| \le \chi, \left|\frac{w_4}{w_3}-1.95\right| \le \chi, \\
\left|\frac{w_2}{w_1}-2.4\right| \le \chi, \\
\sum_{j=1}^{5} w_j = 1,\ w_j \ge 0, \forall j
\end{array}\right.$$

$$Expert\ 6-\min \chi$$

$$\left\{\begin{array}{l}
\left|\frac{w_5}{w_4}-1.2\right| \le \chi,\ \left|\frac{w_4}{w_1}-1.4\right| \le \chi,\ \left|\frac{w_1}{w_2}-1.2\right| \le \chi, \\
\left|\frac{w_2}{w_3}-1.3\right| \le \chi, \left|\frac{w_5}{w_1}-1.68\right| \le \chi, \left|\frac{w_4}{w_2}-1.68\right| \le \chi, \\
\left|\frac{w_1}{w_3}-1.56\right| \le \chi, \\
\sum_{j=1}^{5} w_j = 1,\ w_j \ge 0, \forall j
\end{array}\right.$$

By solving the presented linear programming models, the final values of the weight coefficients of each expert are defined, Table 2. By evaluating the obtained values, the optimal values of the weight coefficients of the criteria were further determined to be used for the evaluation of the routes using TOPSIS and MABAC methods.

Table 2. Calculation of weight coefficients of the criteria

Experts	Weight coefficient of criteria				
	C1	*C2*	*C3*	*C4*	*C5*
E1	0.1017	0.5698	0.0339	0.2849	0.0097
E2	0.0382	0.2932	0.3811	0.1150	0.1724
E3	0.2275	0.1422	0.0981	0.3048	0.2275
E4	0.1171	0.1897	0.1094	0.2561	0.3278
E5	0.0843	0.2023	0.1349	0.2630	0.3156
E6	0.1800	0.1500	0.1154	0.2521	0.3025
Average value	0.1248	0.2579	0.1455	0.2460	0.2259

4.2. Application of the TOPSIS model

The TOPSIS method algorithm is applied to initial decision matrix D:

$$D = \begin{array}{c} route \\ 1 \\ 2 \\ 3 \\ 4 \end{array} \begin{bmatrix} \min f_1 & \min f_2 & \min f_3 & \min f_4 & \min f_5 \\ 3 & 0,65 & 8 & 8 & 232 \\ 2 & 0,50 & 7 & 6 & 233 \\ 1 & 0,45 & 5 & 5 & 250 \\ 1 & 0,20 & 2 & 4 & 280 \end{bmatrix}$$

*Step 1. N*ormalized matrix (X) is obtained by normalizing the elements of initial decision matrix (D), expression (4)

$$X = \begin{bmatrix} \min f_1 & \min f_2 & \min f_3 & \min f_4 & \min f_5 \\ 0,2254 & 0,3205 & 0,3287 & 0,3263 & 0,5351 \\ 0,4836 & 0,4773 & 0,4126 & 0,4947 & 0,5331 \\ 0,7418 & 0,5296 & 0,5804 & 0,5789 & 0,499 \\ 0,7418 & 0,8322 & 0,8322 & 0,6631 & 0,4389 \end{bmatrix}$$

Step 2. By multiplying the normalized matrix and weight coefficients of the criteria, expression (7), a heavier normalized matrix is constructed (8)

$$T = \begin{bmatrix} \min f_1 & \min f_2 & \min f_3 & \min f_4 & \min f_5 \\ 0,0281 & 0,0827 & 0,0478 & 0,0803 & 0,1209 \\ 0,0604 & 0,1231 & 0,06 & 0,1217 & 0,1204 \\ 0,0926 & 0,1366 & 0,0844 & 0,1424 & 0,1127 \\ 0,0926 & 0,204 & 0,1211 & 0,1631 & 0,0991 \end{bmatrix}$$

Step 3. Using expressions (9) and (10) ideal and negative-ideal solutions are calculated:

Ideal solution: A^* = { 0.0926, 0.204, 0.1211,0.1631, 0.12} and

Negative ideal solution: A^-= {0.0281, 0.0827, 0.0478, 0.0803, 0.0991}.

Step 4: Using expressions (11) and (12) Euclidean distance alternatives are calculated from ideal and negative-ideal solutions, Table 3.

Table 3. Distance from ideal and negative-ideal solutions

Alternative	Si^*	Si^-
A1	0.0218	0.1764
A2	0.0707	0.1141
A3	0.1116	0.0799
A4	0.1764	0.0218

Steps 5 and 6. Using expression (13) the relative proximity of the alternatives to the ideal solution is calculated and we get the final rank of the alternative: A4> A3> A2> A1.

4.3. Application of the MABAC model

The MABAC method algorithm applies to the same initial decision matrix D, as well as the TOPSIS model.

Step1: Since all functions of the *min* type are used to normalize the initial matrix of decision making, we use expression (12). By applying this relation we receive a normalized matrix N:

$$N = \begin{array}{c} route \\ 1 \\ 2 \\ 3 \\ 4 \end{array} \left[\begin{array}{ccccc} \min f_1 & \min f_2 & \min f_3 & \min f_4 & \min f_5 \\ 0 & 0 & 0 & 0 & 0 \\ 0,5 & 0,33 & 0,1667 & 0,5 & 0,9792 \\ 1 & 0,44 & 0,5 & 0,75 & 0,625 \\ 1 & 0,95 & 1 & 1 & 1 \end{array} \right]$$

Step 2: In step 2, applying expression (13), elements of a heavy normalized matrix are calculated:

$$V = \begin{array}{c} route \\ 1 \\ 2 \\ 3 \\ 4 \end{array} \left[\begin{array}{ccccc} \min f_1 & \min f_2 & \min f_3 & \min f_4 & \min f_5 \\ 0,1248 & 0,2579 & 0,1455 & 0,246 & 0,2259 \\ 0,1872 & 0,343 & 0,1698 & 0,369 & 0,4471 \\ 0,2496 & 0,3714 & 0,2183 & 0,4305 & 0,3671 \\ 0,2496 & 0,5029 & 0,291 & 0,492 & 0,4518 \end{array} \right]$$

Step 3: In step 3, boundary approximate domain matrix (G) is calculated. Boundary approximation area (GAO) for each criterion is determined according to (18).

$$G = \left[\begin{array}{ccccc} C1 & C2 & C3 & C4 & C5 \\ 0,1954 & 0,3585 & 0,199 & 0,3724 & 0,2597 \end{array} \right]$$

Step 4: Using expression (21) we calculate the elements of a matrix (20), which represents the distance of an alternative to GAO.

$$Q = \left[\begin{array}{ccccc} \min f_1 & \min f_2 & \min f_3 & \min f_4 & \min f_5 \\ -0,0706 & -0,1006 & -0,0535 & -0,1264 & -0,1338 \\ -0,0082 & -0,0155 & -0,0292 & -0,0034 & +0,0874 \\ +0,0542 & +0,0129 & +0,0193 & +0,0581 & +0,0074 \\ +,0542 & +0,1444 & +0,092 & +0,1196 & +0,0921 \end{array} \right]$$

Step 5: Calculation of the value of the criterion functions for each alternative is obtained as the sum of the distance of the alternatives from the boundary approximate fields. By summarizing the elements of the Q matrix in rows, we obtain the final values of the criterion functions of the alternative and the final ranking alternative that reads: A4> A3> A2> A1. In Table 4 a comparative analysis of the route ranges for THM obtained using TOPSIS and MABAC methods is given.

Table 4. Route ranges using TOPSIS and MABAC methods

Route	Rank	
	TOPSIS	MABAC
A1	4	4
A2	3	3
A3	2	2
A4	1	1

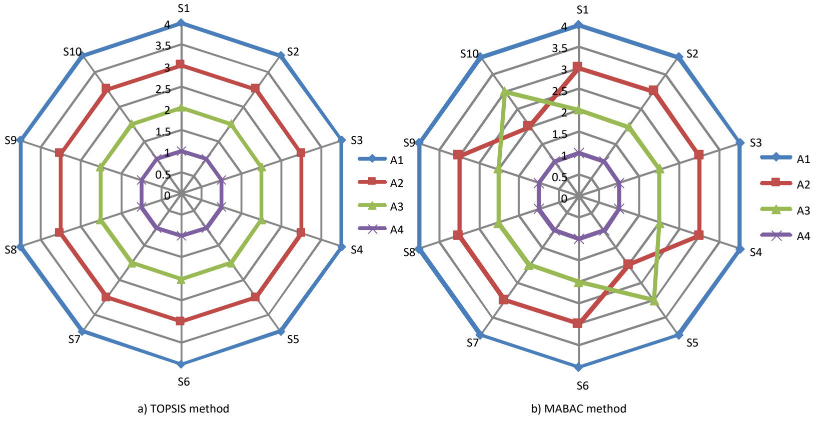
4.4. Sensitivity analysis of the solution

Since the results of multi-criteria decision-making depend on the value of the weight coefficient of the evaluation criteria, in the following section the analysis of the sensitivity of the results to the change in the weight of the criteria is presented. Sometimes the ranking alternatives vary with very small changes in weight coefficients. Therefore, the results of these multi-criteria decision-making methods follow the sensitivity analysis on these changes as a rule. The analysis of the sensitivity of the ranks of alternatives to changes in the weight coefficients of the criteria was carried out through ten scenarios given in Table 5.

Table 5. Scenarios of sensitivity analysis

Scenario	Weight criteria	Scenario	Weight criteria
S1	$w_{c1}=1.25\times w_{c11(old)}$; $w_{ci}=0.25\times w_{ci(old)}$	*S6*	$w_{c1}=1.55\times w_{c11(old)}$; $w_{ci}=0.55\times w_{ci(old)}$
S2	$w_{c2}=1.25\times w_{c11(old)}$; $w_{ci}=0.55\times w_{ci(old)}$	*S7*	$w_{c2}=1.55\times w_{c11(old)}$; $w_{ci}=0.55\times w_{ci(old)}$
S3	$w_{c3}=1.25\times w_{c11(old)}$; $w_{ci}=0.25\times w_{ci(old)}$	*S8*	$w_{c3}=1.55\times w_{c11(old)}$; $w_{ci}=0.55\times w_{ci(old)}$
S4	$w_{c4}=1.25\times w_{c11(old)}$; $w_{ci}=0.25\times w_{ci(old)}$	*S9*	$w_{c4}=1.55\times w_{c11(old)}$; $w_{ci}=0.55\times w_{ci(old)}$
S5	$w_{c5}=1.25\times w_{c11(old)}$; $w_{ci}=0.25\times w_{ci(old)}$	*S10*	$w_{c5}=1.55\times w_{c11(old)}$; $w_{ci}=0.55\times w_{ci(old)}$

The scenarios of the sensitivity analysis are grouped into two phases. Within each phase of the sensitivity analysis, the weight coefficients of the criteria were increased by 25% and 55%, respectively. In each of the ten scenarios, only one criterion is favored for which the weight coefficient is increased for the stated values. In the same scenario, with the remaining criteria, weight coefficients were reduced by 25% (S1-S5) and 55% (S6-S10). Changes in the ranking alternatives during the 10 scenarios in TOPSIS and MABAC methods are presented in Figure1.



a) TOPSIS method

b) MABAC method

Figure 1. Changes in the ranking alternatives in 10 scenarios

The results show that assigning different weight to the criteria through the 10 scenarios shown does not lead to a significant change in the ranking of the alternative. By comparing the first-ranked alternatives (A4 and A3) in scenarios 1-10 with initial rankings from TOPSIS and MABAC models, we note that the rank of first-ranked alternatives is confirmed. By analyzing the rankings through 10 scenarios, we also notice that the A4 alternative in all 10 scenarios has kept its ranking. Based on this, we can conclude that there is a satisfactory closeness of ranks and that the proposed ranking is confirmed and credible.

5. Conclusions

The new FUCOM-TOPSIS-MABAC model for route evaluation for THM is presented here. Verification of the FUCOM-TOPSIS-MABAC model was carried out on a real case from the practice in which the transport of Eurodiesel was considered for the needs of the Ministry of Defense of the Republic of Serbia. One of the contributions of this paper is the new FUCOM-TOPSIS-MABAC model that provides for an objective aggregation of expert decisions. The second contribution of this paper is the development of the linear programming model for determining the weight coefficients of the evaluation criteria, which contributes to the improvement of the literature that considers the theoretical and practical application of multi-criteria techniques. The third contribution of this study is to improve the methodology of route evaluation for THM through a new approach to determining the weight coefficient of the criteria.

Using the hybrid FUCOM-TOPSIS-MABAC model, it is possible to solve the problems of multi-criteria decision-making in a simple way and make decisions that have a significant impact on increasing safety and reducing risk in THM. The analysis of the results shows that the ranks of the alternatives using the LP-TOPSIS model are in complete correlation with the obtained ranks of the LP-MABAC model. In selecting the most suitable route for THM, both methods (FUCOM-TOPSIS and FUCOM-MABAC) from the aspect of stability of the obtained results prove to be reliable. This was confirmed by analyzing the sensitivity of multi-criteria techniques, which was done through ten scenarios.

Further research related to this paper relates to the post analysis of the internal transport in the observed company in order to verify the minimization of risks arising from the proposed method of organization of THM. When it comes to the field of multi-criteria decision-making, further research directions relate to the application of uncertain theories in combination with other methods and the attempt to develop new hybrid models that would further enrich this widely applied field.

References

Bandyopadhyay, S., & Bhattacharya R. (2013). Finding optimum neighbor for routing based on multi-criteria, multi-agent and fuzzy approach. Journal of Intelligent Manufacturing, 26(1), 1–18.

Chang, C.H., Lin, J.J., Linc, J.H., & Chiang, M.C. (2010). Domestic open-end equity mutual fund performance evaluation using extended TOPSIS method with different distance approaches. Expert Systems with Applications, 37(6): 4642-4649.

Das, A., Mazumder, T.N., & Gupta, A.K. (2012). Pareto frontier analyses based decision making tool for transportation of hazardous waste. Journal of Hazardous Materials, 227-228, 341–52.

Dilgir, R., Zein, S., & Popoff, A. (2005). Hazardous goods route selection criteria. Annual Conference of the Transportation Association of Canada, Calgary – Alberta.

Erkut, E., & Verter V. (1998). Modeling of transport risk for hazardous materials. Operations Research, 46(5), 625-642.

Gigovic, LJ., Pamucar, D., Bozanic, D. & Ljubojevic, S. (2017). Application of the GIS-DANP-MABAC multi-criteria model for selecting the location of wind farms: A case study of Vojvodina, Serbia. Renewable Energy, 103, 501-521.

Huang B. (2006). GIS-Based Route Planning for Hazardous Material Transportation, Journal of Environmental Informatics, 8(1), 49-57.

Huang, B., & Fery, P. (2005). Aiding route decision for hazardous material transportation, TRB 2005 Annual Meeting.

Huang, B., Long Cheu, R., & SengLiew, Y. (2004). GIS and genetic algorithms for HAZMAT route planning with security considerations. International Journal of Geographical Information Science, 18(8), 769-787.

Jia, S.J., Yi, J., Yang, G.K., Du, B., & Zhu, J. (2013). A multi-objective optimisation algorithm for the hot rolling batch scheduling problem. International Journal of Production Research, 51(3), 667-681.

Law, V., & Rocchi, S. (2008). Hazardous goods route study, Final report city of Prince George.

Li, R., & Leung, Y. (2011). Multi-objective route planning for hazardous goods using compromise programming. Journal of Geographical Systems, 13(3), 249–271.

Long, C.R., & Liew, Y.S. (2003). GIS-AHP model for HAZMAT routing with security considerations. Intelligent Transportation Systems, 3, 1644–1649.

Milovanovic, B. (2012). Prilog razvoju metodologije za izbor trasa za kretanje vozila koja transportuju opasnu robu sa aspekta upravljanja rizikom, Beograd, Saobracajni fakultet Univerziteta u Beogradu. (in Serbian).

Monprapussorn, S., Watts, D., & Banomyong, R. (2009). Sustainable hazardous materials route planning with environmental consideration. Asian Journal on Energy and Environment, 10(2), 122-132.

Oluwoye, J. (2000). Transportation of hazardous goods and the environment: a conceprual framework of the planning for classification procedure of hazardous e goods, South African Transport Conference, South Africa.

Pamucar, D., & Cirovic, G. (2015). The selection of transport and handling resources in logistics centres using Multi-Attributive Border Approximation area Comparison (MABAC). Expert Systems with Applications, 42, 3016- 3028.

Pamucar, D., Ljubojevic, S., Kostadinovic, D., & Djorovic, B. (2016). Cost and Risk aggregation in multi-objective route planning for hazardous materials transportation - A neuro-fuzzy and artificial bee colony approach. Expert Systems with Applications, 65, 1-15.

Pamucar, D., Petrovic, I., & Cirovic, G. (2018). Modification of the Best-Worst and MABAC methods: A novel approach based on interval-valued fuzzy-rough number. Expert Systems with Applications, 91, 89-106.

Pamucar, D., Stevic, Z., & Sremac, S. (2018). A New Model for Determining Weight Coefficients of Criteria in MCDM Models: Full Consistency Method (FUCOM). Symmetry, 10(9), 393.

Peng, X., & Dai, J. (2016). Approaches to single-valued neutrosophic MADM based on MABAC, TOPSIS and new similarity measure with score function. Neural Computing and Applications, 29(10), 939–954.

Peng, X., & Yang, Y. (2016). Pythagorean Fuzzy Choquet Integral Based MABAC Method for Multiple Attribute Group Decision Making. International Journal of Intelligent Systems, 31(10), 989–1020.

Roy, J., Ranjan, A., Debnath, A., & Kar, S. (2016). An extended MABAC for multi-attribute decision making using trapezoidal interval type-2 fuzzy numbers. Artificial Intelligence, arXiv:1607.01254.

Samuel, C. (2007). Frequency analysis of hazardous material transportation incidents as a function of distance from origin to incident location, Iowa, Iowa State University.

Sattayaprasert, W., Taneerananon, P., Hanaoka, S., & Pradhananga, R. (2008). Creating a risk-based network for HAZMAT logistics by route prioritization with AHP. IATSS Research, 32(1), 74–87.

Song, W., Ming, X., Wu, Z., & Zhu, B. (2014). A rough TOPSIS approach for failure mode and effects analysis in uncertain environments. Quality and Reliability Engineering International, 30(4), 473-486.

Srdjevic, B., Srdjevic, Z., & Zoranovic, T. (2002). PROMETHEE, TOPSIS i SP u višekriterijumskom odlucivanju u poljoprivredi, Letopis naucnih radova, 26(1), 5 – 23. (in Serbian).

Stevic, Z., Tanackov, I., Vasiljevic, M., Novarlic, B., & Stojic, G. (2016). An integrated fuzzy AHP and TOPSIS model for supplier evaluation. Serbian Journal of Management, 11(1), 15-27.

Talarico, L. (2015). Secure Vehicle Routing: models and algorithms to increase ecutity and reduce costs in the cash-in-transit sector. Faculty of Applied Economics, Universitas, Antwerp.

Verma, M. (2011). Railroad transportation of hazardous goods : A conditional exposure approach to minimize transport risk. Transportation Research Part C: Emerging Technologies, 19(5), 790–802.

Wijeratne, A., Turnquist, M., & Mirchandani, P. (1993). Multiobjective routing of hazardous materials in stochastic networks. European Journal of Operation Research 65(1), 33-43.

Xue, Y.X., Youa, J.X., Laic, X.D., & Liu, H.C. (2016). An interval-valued intuitionistic fuzzy MABAC approach for material selection with incomplete weight information. Applied Soft Computing, 38, 703–713.

Yu, S., Wang, J., & Wang, J. (2016). An Interval Type-2 Fuzzy Likelihood-Based MABAC Approach and Its Application in Selecting Hotels on a Tourism Website. International Journal of Fuzzy Systems, 19(1), 47-61.

Zhang, Y., Zhang, Y., Li, Y., Liu, S., & Yang, J. (2017). A Study of Rural Logistics Center Location Based on Intuitionistic Fuzzy TOPSIS. Mathematical Problems in Engineering, Article ID 2323057, https://doi.org/10.1155/2017/2323057.