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Original Article

FUZZY TOPSIS IN SELECTING LOGISTIC HANDLING OPERATOR: CASE STUDY FROM POLAND

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Highlights:
- a MCDM approach under partial or incomplete information is presented;
- criteria for carrier selection depending on the type of transported cargo are proposed;
- fuzzy TOPSIS approach for selecting a logistic handling operator is introduced;
- a logistic handling operator selection process for transportation company is illustrated;
- traditional and fuzzy-based approaches for a carrier selection process are compared.

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Abstract. Reliable and effective selection of logistic handling operator is a particularly demanding process due to the short reaction time or high level of accompanying stress. Moreover, diversification of transported cargo makes use of classical indicators and methods of carrier selection highly unsatisfactory for decision-makers. To solve this problem, managers are seeking multi-criteria decision methods that improve the decision-making process related to the selection of the carrier and reduce the risk indicator related to the incorrect implementation of the transport order. Thus, in this paper, we present a Multi-Criteria Decision-Making (MCDM) approach for selecting logistic handling operators under partial or incomplete information (uncertainty) and taking into account the different type of transported cargo. The proposed approach comprises 2 main steps. In the 1st step, we identify the input parameters, mainly connected with criteria for carrier selection depending on the type of transported cargo. In the 2nd step, experts provide linguistic ratings to the potential alternatives against the selected criteria and the best alternative is chosen. At this stage, the fuzzy Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) approach is used. Later, the applicability of the developed method is presented based on the chosen case company. The comparison of classical and fuzzy approaches to decision-making process is also given.

Keywords: multi-criteria decision-making (MCDM), fuzzy TOPSIS, fuzzy theory, carrier selection, cargo type, uncertainty.

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Notations

Abbreviations:

ADR – the European agreement concerning the international carriage of dangerous goods by road;
ANP – analytic network process;
ARAS – additive ratio assessment;
CFN – convex fuzzy number;
DEA – data envelopment analysis;
DEMATEL – decision-making trial and evaluation laboratory;
ELECTRE – elimination and choice translating reality (in French – *ÉLimination Et Choix Traduisant la REalité*);
FCL – full container load;
FN – fuzzy number;
GPS – global positioning system;
HACCP – hazard analysis and critical control point;
JiT – just in time;
LCL – less than container load;
MCDM – multi-criteria decision-making;
NIS – negative ideal solution;
OTIF – on time in full;
PIS – positive ideal solution;
PROMETHEE – preference ranking organization method for enrichment of evaluations;
SAW – simple additive method;
SMART – simple multi-attribute rating technique;
SWARA – step-wise weight assessment ratio analysis method;
TOPSIS – technique for order performance by similarity to ideal solution;

UN – unit number;
VIKOR – multi-criteria optimization and compromise solution (in Serbian: *Višekriterijumska optimizacija I KOmpromisno Rešenje*);
WASPAS – weighted aggregated sum product assessment;
WPM – weighted product model;
WSM – weighted sum model.

Main variables and functions:

a_{ij}^l – the lower bound of fuzzy number x_{ij}^l;
A^{l+} – fuzzy PIS for the given individual product group G_l;
A^{l-} – fuzzy NIS for the given individual product group G_l;
B_i^l – set of alternatives for lth cargo group, where i = (1, 2, 3, ..., M);
b_{ij}^l – the modal value of fuzzy number x_{ij}^l;
C_b^l – set of benefit criteria for a given cargo group G_l;
C_c^l – set of cost criteria for a given cargo group G_l;
c_{ij}^l – the lower bound of fuzzy number x_{ij}^l;
C_j^l – set of criteria that are assigned to lth cargo group, where j = (1, 2, 3, ..., N);
D_k – an amount of decision makers, where k = (1, 2, 3, ..., K);
d_i^{l+} – relative closeness of each alternative to the ideal solution A^{l+} for the given individual group of products;
d_i^{l-} – relative closeness of each alternative to the anti-ideal solution A^{l-} for the given individual group of products;
G_l – set of cargo groups, where l = (1, 2, 3, ..., L);
RC_i^l – rank indicator for assessed alternatives;
$R_G(l)$ – normalized fuzzy decision matrix for alternatives with respect to criteria and product groups;
r_{ij}^l – normalized rating of alternative B_i^l with respect to criterion C_j^l for the given individual product group G_l;
$V_G(l)$ – weighted normalized fuzzy decision matrix for alternatives with respect to criteria and product groups;
v_{ij}^l – weighted rating of alternative B_i^l with respect to criterion C_j^l for the given individual product group G_l;
v_j^{l+} – ideal solution for jth criterion for lth individual group of products;
v_j^{l-} – anti-ideal solution for jth criterion for lth individual group of products;
W_j^l – vector of criteria weights for a given individual product group G_l;
w_j^l – weight for jth criterion being assigned to lth cargo group;
$X_G(l)$ – fuzzy decision matrix for alternatives with respect to criteria and product groups;
x_{ij}^l – aggregated fuzzy ratings of alternative B_i^l with respect to criterion C_j^l for the given individual product group G_l evaluated by every expert D_k, where k = (1, 2, 3, ..., K);
x_{ijk}^l – fuzzy ratings of alternative with respect to criterion C_j^l for the given individual product group G_l evaluated by kth expert.

Introduction

Nowadays, a process of carrier selection is one of the most important decisions in the transportation strategic planning. The proper organization and performance of this process influences both, logistics cost and customer service within the whole supply chains. However, this process is a complex problem, where managers have to consider multi-criteria, quantified and not quantified. Moreover, the importance of these criteria often differs from industry to industry.

In the early studies, this decision process consisted with 2 main steps. The 1st step based on the mode of transportation definition. The next step was connected with selection of the carrier active in that mode (Baker 1984; Coyle *et al.* 2003). However, recently such approach is ineffective due to high development of transportation technology and third-party logistics organizations, deregulation of transportation systems, implementation of innovative manufacturing strategies (e.g., JiT strategy), and growing competition between different transportation modes (Meixell, Norbis 2008; Mohammaditabar, Teimoury 2008). The 2nd problem is connected with the carrier selection criteria definition. According to Roberts (2012) we are able to identify an extensive list of potential factors that may influence the carrier selection decision-making process. This problem is reviewed by Mohammaditabar & Teimoury (2008). Moreover, Perlman *et al.* (2009) defined the key factors in selecting international freight forwarding company based on the use of survey research. The survey was carried out through 200 Israeli exporters and importers, who defined 18 factors for carrier selection process. The summary of key development of carrier selection literature on survey methodology performance is later given in research by Solakivi & Ojala (2017). However, one common opinion from the literature is missing, which of these selection factors are the most important and how they should be grouped (Perlman *et al.* 2009).

The problem of carrier selection decision-making processes was also investigated by the authors in Polish transportation enterprises. The main conclusion is that shippers in Poland do not have tools to support their decision-making processes regarding the selection of carriers. Decisions made under short time conditions and high levels of stress mean that these decision-makers are usually focused on strict criteria regarding the selection of the service provider. Thus, the diversification of transported loads means that the use of universal supplier selection indicators is currently unsatisfactory for people managing this cargo handling zone. Moreover, decisions made by freight forwarders depend on the experience level gained while handling individual cargo groups. Thanks to this, employees with extensive experience in handling loads of a given type make decisions with a lower risk ratio than people who do not have this experience.

However, from the point of view of the load handling process resilience, relying on the diverse experience of employees is unacceptable from the point of view of improving decision-making processes in the enterprise. Currently, this problem especially regard to operating transport management systems in Polish enterprises. Studies carried out in selected road transport companies indicate that 75% of freight forwarders currently employed by road carriers are young people with experience of up to 3 years[*]. This means that these people do not have extensive knowledge about handling loads belonging to different product groups. It is therefore necessary to provide them with a model solution that will support and improve the decision-making process associated with the carrier selection and reduce the risk index associated with incorrect execution of the transport order. In order to satisfy such the requirements, the comprehensive decision method/model should consider a variety of decision variables and uncertain information given to the decision maker. Thus, 1st the proposed solution for carrier selection is to be based on multi-criteria approaches implementation in order to satisfy different types of requirements and transport process conditions. 2nd, the applied method uses fuzzy environment. Moreover, the additional advantage of the proposed framework is the ability of a decision maker to distinguish the type of criteria (benefit, cost) with respect to the defined group of transported products.

Following the introduction, the current systems of selecting carriers to handle transport orders by logistics operators are burdened with a high risk of wrong forwarders' decisions. The lack of specific requirements regarding the selection of the carrier for the specificity of the transported load (apart from formal requirements, e.g., ADR competence certificates) and the high weight assigned to the cost criterion means that the decisions taken by forwarders can be burdened with a very high risk of possible adverse events occurrence. This is particularly the case for sensitive goods for which there are no formal requirements for carriers (resulting from legal provisions) to be fulfilled.

As a result, the purpose of the publication is to present the limitations resulting from the traditional approach to the process of selection of the carrier by the logistics operator and to present the new proposed method that reduces the risk of wrong decisions making by the forwarder.

[*] Based on Research Project MINIATURA 1: *Identification of Information Sets Supplying the Risk Assessment System in Road Transport in Terms of Safety and Compliance with Logistics Standards*. National Science Centre (Poland); time period: 1 December 2017 – 30 November 2018.

The main research questions, stated by the authors are:

- does the traditional approach to the selection of the carrier ensure the correct selection of the service provider based on the criterion of safety and reliability of transport performance with respect to various groups of goods?
- will the use of the proposed method of carrier selection reduce the risk of adverse events, in particular for the transport of sensitive goods?

Following this, in this paper we present a MCDM approach for evaluation and selection of the best logistic handling operator under uncertain (fuzzy) environment and taking into account the type of transported products as the main attribute. Following this, the rest of the paper is organized as follows: In Section 1 there is presented a comprehensive literature review on multi-criteria decision methods used in transportation systems. In the Section 2, the authors present the traditional process of logistic handling operator selection based on the industrial research. In the Section 3, there is explained in details the proposed framework for carrier selection based on fuzzy TOPSIS approach implementation. The Section 4 provides a case study of the proposed framework implementation in Polish enterprises. The last section contains conclusions and presents steps for further authors' research in this area.

1. Multi-criteria decision methods in transportation systems – literature review

There are several approaches that are used to solve transportation problems. MCDM techniques are one of them. In recent years, numerous MCDM and fuzzy MCDM approaches have been suggested to select the best compromise options (Mardani *et al.* 2016a, 2016b).

A short introduction to the multi-criteria discrete decision methods is given in research by Trzaskalik (2014). The author in his work presents the most frequently used methods and provides their short classification based on application possibilities. A bibliometric analysis of research on MCDM dated from 1977 to 2016 is provided in work by Yu *et al.* (2018). A review on fuzzy MCDM techniques and their applications is given in work by Asemi *et al.* (2014). The authors selected 150 articles that were focused on decision-making based on fuzzy MCDM techniques use. The main fields of applications that were reviewed regarded to, among others, supplier selection, water resources, energy planning, network selection, transportation planning, risk management, and location management. Another interesting work dedicated to fuzzy MCDM (Carlsson, Fullér 1996). The authors in their work continued the problem of decision-making with fuzzy MCDM, provided a classification of fuzzy MCDM techniques. They also presented future perspectives of fuzzy MCDM development. Later, Mardani *et al.* (2015) provide a literature review of total of 403 papers published from 1994 to 2014 and focused on fuzzy MCDM techniques use. The analysed literature was grouped into 4 main fields: (1) engineering; (2) management and business; (3) science; (4) technology. This problem was also continued in work (Mardani *et al.* 2017c), where the authors reviewed 196 papers on fuzzy MCDM techniques dated from 1995 to 2015. All the investigated papers were classified into 13 different fields of energy management problems, like, e.g., waste management, sustainability assessment, land management, or climate change.

The issues of uncertainty modelling in MCDM are reviewed in work by Antucheviciene *et al.* (2015). The authors analysed MCDM techniques in relation to various aspects of uncertainty in civil engineering, e.g., sensitive analysis, measures of risk and reliability or decision-making under uncertainty. Sustainable decision-making in civil engineering was later analysed by Zavadskas *et al.* (2018).

Reviews of hybrid MCDM techniques are given, e.g., in research by Zavadskas *et al.* (2016a, 2016b). In the work by Zavadskas *et al.* (2016b), the authors summarized publications related to the application of hybrid MCDM for sustainability issues. The 2nd work by Zavadskas *et al.* (2016a) was focused on engineering problems. The application of MCDM methods in engineering problems was also reviewed in work by Kolios *et al.* (2016), where the authors compared 6 MCDM methods that are frequently used on renewable energy applications.

Worth taking a note is also work given by Celik *et al.* (2019), where the authors focused on stochastic MCDM approaches. The stochasticity of the criteria is there considered using stochastic dominance, prospect theory, and regret theory. The review regarded 61 selected papers.

Following this short introduction, among the most popular MCDM methods there are identified:

- AHP (Subramanian, Ramanathan 2012);
- ANP (Saaty 2005);
- ARAS (Zavadskas, Turskis 2010);
- DEA (Charnes *et al.* 1978; Shafiei Kaleibari *et al.* 2016; Mardani *et al.* 2017b);
- DEMATEL (Fontela, Gabus 1976; Si *et al.* 2018);
- ELECTRE (Figueira *et al.* 2010);
- PROMETHEE (Behzadian *et al.* 2010);
- SAW (Abdullah, Adawiyah 2014; Putra, Punggara 2018);
- SMART (Edwards, Barron 1994; Olson 1996);
- SWARA (Keršulienė *et al.* 2010; Mardani *et al.* 2017a);
- VIKOR (Mardani *et al.* 2016a);
- WASPAS (Mardani *et al.* 2017a; Zavadskas *et al.* 2012);
- WPM (Miller, Starr 1969; Wao 2018);
- WSM (Miljković *et al.* 2017; Fishburn 1967);
- TOPSIS (Anthony *et al.* 2019; Behzadian *et al.* 2012).

The comprehensive literature review on MCDM techniques application in transportation systems is given in research by Mardani *et al.* (2016b). The authors analysed 89 papers based on areas of application and used technique.

The main transportation problems being solved with the use of MCDM methods regard to, among others, delivery route selection (Kacprzak, Rudnik 2016), finding the shortest path (El Yamani *et al.* 2014), customer service quality management (Lwesya, Jaffu 2017), synchromodality and sustainability implementation (Cadena, Magro 2015; Šakalys *et al.* 2019), decision-making processes in urban transportation system projects (Podvezko, Sivilevicius 2013; Żak *et al.* 2014), and supply chains development (Amoozad Mahdiraji *et al.* 2018; Chaghooshi, Hajimaghsoudi 2014) and supply chains management (Chatterjee, Stević 2019).

The problem of freight transportation carrier selection is investigated, e.g., in work by Mohammaditabar, Teimoury (2008). The authors in their work implemented AHP techniques and objective mixed integer linear programming model of product flow in the network. The analysed carrier selection criteria regarded to cost, insurance of service provision, handling services, customer service and strategic compatibility. The PROMETHEE method is used in work by Simongáti (2010) to find the sustainable alternative for freight transport performance based on freight integrator development.

There are also many applications of fuzzy TOPSIS approach in the transportation decision-making processes. The general view of the development of fuzzy TOPSIS methods is given in paper by Nădăban *et al.* (2016). The literature survey on TOPSIS applications is also given in work by Behzadian *et al.* (2012). The authors review 266 papers and classify them into 9 main areas, distinguishing among others supply chain management and logistics.

The implementation of fuzzy TOPSIS approach for selection of sustainable transportation systems is given in work by Awasthi *et al.* (2011). The analysis is based on the 24 selection criteria that were identified by the authors from literature review. The problem of transportation mode selection with the use of fuzzy TOPSIS approach is investigated, e.g., in work by Zheng (2015). In the given paper the author analyses the travel behaviour of students and modes selection in suburban area. The fuzzy TOPSIS approach with the use of ordered FNs is investigated in papers by Rudnik & Kacprzak (2015, 2017). The Rudnik & Kacprzak (2015) in their work implement that approach for supplier selection process. In the 2nd paper, the authors provide the implementation for flow controller for the transport trolley in a flexible manufacturing system. The problem of supplier evaluation with fuzzy approach is also analysed by the Stević *et al.* (2016). The implementation of fuzzy QFD and TOPSIS in maritime transportation is presented in research by Osorio Gómez & Manotas Duque (2019). In the given paper the authors focus on dispatching prioritization according to the availability of resources and considering the risks associated with the decision-making process.

Moreover, in the literature one can find many extensions of the classical fuzzy TOPSIS approach. One of them is given by Dymova *et al.* (2013). The authors in this work present a new method of aggregations generalization within the framework of the fuzzy extension of the TOPSIS method. Later, the Kacprzak (2018) is his work presents a new approach to the ranking of alternatives with interval data for group decision-making. The solution bases on interval numbers implementation. A computer tool for supporting the implementation of fuzzy TOPSIS approach is proposed in research by Roszkowska & Wachowicz (2013). The authors develop a software that bases on *Microsoft Excel* spreadsheet and supports a decision-maker through all the steps of TOPSIS and fuzzy TOPSIS method implementation.

Following this, in the next sections the classical process of logistic handling operator selection and application of fuzzy TOPSIS approach in this area are investigated.

2. Process of logistic handling operator selection

The decision process related to carrier selection in its classical form is understood as procedures that have been obligatory for many years in Polish transport and logistics companies. It bases on standardization of the selection procedure for all product groups, except for loads for which legal regulations require an individualized vehicle (e.g., ADR loads). The dominant criterion for carrier selection is the price offer, which is assigned the highest weight. The assessment is based on a simple scoring method use. The main steps of the analysed process are presented below.

The forwarder, after receiving an order, analyses the availability of possible carriers, who may operate on the selected route. The decision maker usually has the following information available:

- a list of own fleet and disposable drivers;
- list of carriers cooperating with the logistics operator on a partnership basis (permanent cooperation);
- list of carriers that have been commissioned once for selected transport orders (temporary cooperation);
- carriers from the freight exchange.

The freight forwarder, when choosing the carrier usually follows the general rules that apply to most logistics operators in Poland:

- first of all, order loads based on own transport fleet, but with respect to effective transportation performance (filling the cargo area in accordance with the economic calculation – “profitable”);
- if you cannot commission a transport service of your own transport fleet, check the availability of carriers cooperating in partner relations;
- if both variants are not available, hand it over to the available carrier.

It can therefore be concluded that the accessibility criterion is a prerequisite for subcontracting cargo transport service performance. However, the 1st selection criterion in this case is the cooperation of an operator with a given carrier. It results from the above rules, which impose on the forwarder the selection rank for a subcontractor. However, despite the availability of partner carriers the freight forwarders often search for transport provider at freight exchanges. This is mainly due to the fact that the 2nd equally important selection criterion is the freight price offered by the carrier. It often occurs, that the decision, which carrier will be contracted to an external service is based on the level of offered price. In addition, experienced forwarders check, before commissioning the transport the timeliness and the amount for which the carrier is insured. The control of an insurance policy is particularly important when the transport order concerns the transport of sensitive or valuable goods.

Such a formulated operational workflow at the stage of selecting carriers to handle a transport order causes that the risk of adverse events occurrence increases. Therefore, it should be recognized that one of the basic principles of sustainable development in the field of transport, namely “strengthening transport safety and security” is not respected EC (2007). Carriage carried out by accidental/random carrier means that both, the cargo and the entire delivery process may not be carried out in a safe manner in accordance with the client’s requirements and legal regulations.

Based on the results of “what–if” analysis carried out among freight forwarders at one of the logistics operators, there have been defined basic adverse events and their potential consequences related to the implemented system of selecting the carrier for a transport order. These events can generate consequences for both, the logistics operator and the environment. The Table 1 shows the most important identified adverse events with their consequences and an indication of who these consequences refer to.

The basic problem that currently occurs in the process of ordering the handling of cargoes to the carrier is the lack of diversification of procedures for selecting a subcontractor with respect to the cargo being served. Freight forwarders with extensive experience in the subcontracting process of cargo transport add additional assessment/verification parameters. However, this additional evaluation is informal (not results of applicable service standards). In addition, the parameters taken into account are additional criteria with low decision weight. Meanwhile, in the case of selected product groups, they should be a criterion of high decision weight, often conditional on the admission of the carrier for evaluation, e.g., additional insurance in the event of unauthorized entry into the vehicle when transporting food. This applies especially to special loads, such as sensitive goods, hazardous materials or food.

For this reason, the starting point in the process of selecting a carrier to handle a transport order should be the product group to which the order applies. The conducted direct interviews among road transport companies indicate that it is justified to distinguish the following groups of cargo due to their content:

- ***standard loads*** – products that do not require special transport conditions, to which standard security and logistic handling procedures are applied. Their value is average. No special permissions are required for the driver performing the carriage. There are no additional requirements regarding the route of carriage;

Table 1. Unwanted events with their consequences connected with applied system of carrier selection (source: own contribution)

Unwanted event	Consequences	Area of influence
Theft/loss of cargo	▪ financial penalties from the client; ▪ loss of the market brand; ▪ loss of client's trust; ▪ increased fees for compulsory insurance; ▪ reduction of indicators regarding the reliability of deliveries; ▪ in the case of valuable and sensitive cargo financial crisis	▪ logistic operator; ▪ carrier
Damage to the load	▪ financial penalties from the client; ▪ loss of client's trust; ▪ increased fees for compulsory insurance; ▪ reduction of complete delivery rates; ▪ in the case of ADR loads, the possibility of contamination of all transported products and contamination of the natural environment	▪ logistic operator; ▪ carrier; ▪ environment
Untimely delivery	▪ financial penalties from the client; ▪ reduction of indicators regarding the reliability of deliveries	▪ logistic operator; ▪ carrier
No required, correct documentation	▪ late payment; ▪ reduction of logistic service indicators	▪ logistic operator; ▪ carrier
Failure to comply with customer service requirements	▪ financial penalties from the client; ▪ loss of client's trust; ▪ loss of long-term projects	▪ logistic operator; ▪ carrier
Exceeding the weight of the vehicle	▪ destruction of road infrastructure; ▪ increased emissions to the environment; ▪ penalties for failure to comply with applicable regulations	▪ environment; ▪ carrier
Exceeding the driver's working time	▪ penalties for failure to comply with applicable regulations; ▪ increased risk of causing a traffic accident; ▪ driver's health loss	▪ environment; ▪ carrier
Transport conditions not satisfied	▪ financial penalties from the client; ▪ loss of client's trust; ▪ in the case of ADR loads, the possibility of contamination of all transported products and contamination of the natural environment'; ▪ in the case of food loads, it is necessary to dispose of all transported goods	▪ logistic operator; ▪ carrier; ▪ environment

- ***sensitive loads*** – products that require additional protection due to the value of the load or its specificity (e.g., tobacco, electronic equipment). In connection with this, special logistic and insurance service procedures are required. The value of the load is usually high. No special entitlements are required for the driver performing the transport, but in many cases additional requirements are defined for the route of transport, e.g., obligatory driver's stops only in guarded parking lots;
- ***food loads*** – products requiring special transport conditions, to which dedicated procedures for securing cargo against pollution, pests and specific parameters of logistic service are applied. Their value may be average. The transport is carried out with a special fleet of vehicles that meets the relevant requirements and has appropriate certificates (e.g., proper Veterinary Inspection or District Sanitary Inspector). The carrier must have appropriate certificates attesting to meeting the high standards required in the transport of food, e.g., ISO 22000:2018, HACCP system. There are no additional requirements regarding the route of carriage;
- ***ADR loads*** – in accordance with the ADR agreement guidelines, the transport of dangerous goods is subject to special orders and prohibitions – regarding the admission of material for transport, its packaging, classification and labelling, and requirements relating to the means of transport and transport. Thanks to this classification, dangerous goods are assigned to the methods of choosing the right mode of transport, appropriate packaging and procedures to ensure safety. All hazardous materials produced in the world are divided into 13 hazard classes. Each item has an individual UN identification number. After qualifying the product to the appropriate group and giving it the number, the appropriate means of transport and the appropriate packaging of the goods are selected. The transport process must meet certain parameters of logistic service (including the selection of appropriate cargo loading technology). The packaging is selected in accordance with the degree of risk posed by the load. Thus, materials posing a high risk are included in the I group of packaging, materials posing a medium threat to the II group and materials posing a small threat to the III group of packaging. The marking should be durable and legible, resistant to the influence of external factors. In addition to the labels, warning labels are also used, for example on the type of material being transported. The sender of the cargo also includes the choice of a dangerous cargo transport method. The value of the cargo is usually medium. Transport is carried out by a special fleet of vehicles that meets the relevant requirements (including a speed limiter installed), is specially marked (information about the transported

cargo), has adequate equipment (emergency equipment and fire extinguishers), and has appropriate certificates (according to requirements of the ADR agreement, e.g., a certificate of admission of a vehicle for the transport of certain dangerous goods). In the case of a container, if the road transport is carried out directly before sea transport performance, a container packing certificate is required. The carrier must have appropriate permits for the carriage of certain goods and employ a special adviser for safety. The driver must familiarize himself with the so-called written instruction prior to transport, he is obligated to have a certificate of driver training (if required) and the so-called driver qualification certificate. When planning a dangerous cargo transport route, additional requirements should be taken into account (e.g., passing a vehicle with hazardous material should take place, if possible, on roads with good surface and low traffic, avoiding roads near active holiday and sports centers, and avoiding built-up roads and areas of cities, in particular streets located in the city center. The planned trip should also avoid, if possible, the need to park, especially in urban areas). Some types of materials (e.g., Class 7 – radioactive) are subject to the obligation to report to the competent provincial head of the police and the State Fire Service. Certain types of materials also require the permission of a local police station or a post and commander of the State Border Guard to perform loading and unloading.

The type of transported cargo should be the starting point for selecting the right carrier. Thanks to this, the qualification procedure takes into account the specificity of the transported goods and the selection of subcontractors may correspond to the rules of sustainable transport. In this way, the company is to meet the requirement for safe transport, as it provides the cargo being transported at the required level. This procedure was described by the authors as the procedure of a customized selection of the carrier.

The procedure of customized selection of the carrier assumes that the identification of assessment parameters for individual product groups includes 2 types of possible criteria of: (1) a mandatory (admitting); (2) evaluation nature. The necessary (mandatory) criteria are the conditions that the carrier must meet in order to be admitted to the qualification procedure. The evaluation criteria are the parameters assessing the carrier's offer, which determine the final choice (Table 2).

Based on the obtained results, the process of carrier selection should base on the method that gives the possibility to rank these criteria. On the other hand, is should take into account the uncertainty connected with their estimation. Thus, the authors propose to implement fuzzy TOPSIS approach.

3. Fuzzy TOPSIS approach in logistic handling operator selection process

According to the introduction, it is often difficult for a decision-maker to assign a precise performance rating to an alternative under consideration. In other words saying, in real life decision-making problem it is usually difficult to express evaluations precisely using real numbers due to lack of knowledge and data or subjective and imprecise experts judgements. In the carrier selection process this problem may be also connected with, e.g., not precise definition of shipment time or service flexibility. Thus, there can be used fuzzy theory in decision-making process, where FNs are defined instead of precise numbers in order to assign a relative importance of attributes. Such methods are used for solving the group decision-making problem under fuzzy environment (Kabir, Hasin 2012).

The most commonly used in such situations are linguistic variables, which may be represented by CFNs. Triangular CNFs are one of the alternatives, which can be used for evaluation of importance of weights and the evaluation of alternatives, which respect to each defined criterion (Nădăban *et al.* 2016).

In the known literature, there are also solutions that base on ordered FNs implementation (Rudnik, Kacprzak 2017).

Following this, the proposed framework for carrier selection under uncertainty consists of 2 main steps:

- definition of input variables that are important in carrier selection process performance;
- evaluation and selection of the best alternative using selected criteria and based on fuzzy TOPSIS implementation.

These 2 main steps are presented in detail in Figure 1 and described in the next subsections.

Table 2. Type of assessment parameters according to the individual product groups (source: own contribution)

Criterion	Cargo type			
	Standard products	Sensitive products	Food	ADR products
Price	E	E	E	E
The required amount of insurance	E	M	E	M
Required certificates	E	E	M	M
Required experience in cooperation with the operator (years or number of orders handled)	E	E	E	E
Required level of OTIF index from last year or last 10 performed deliveries	E	E	E	E
Drivers' qualifications	E	E	E	M

Notes: M – mandatory; E – evaluative.

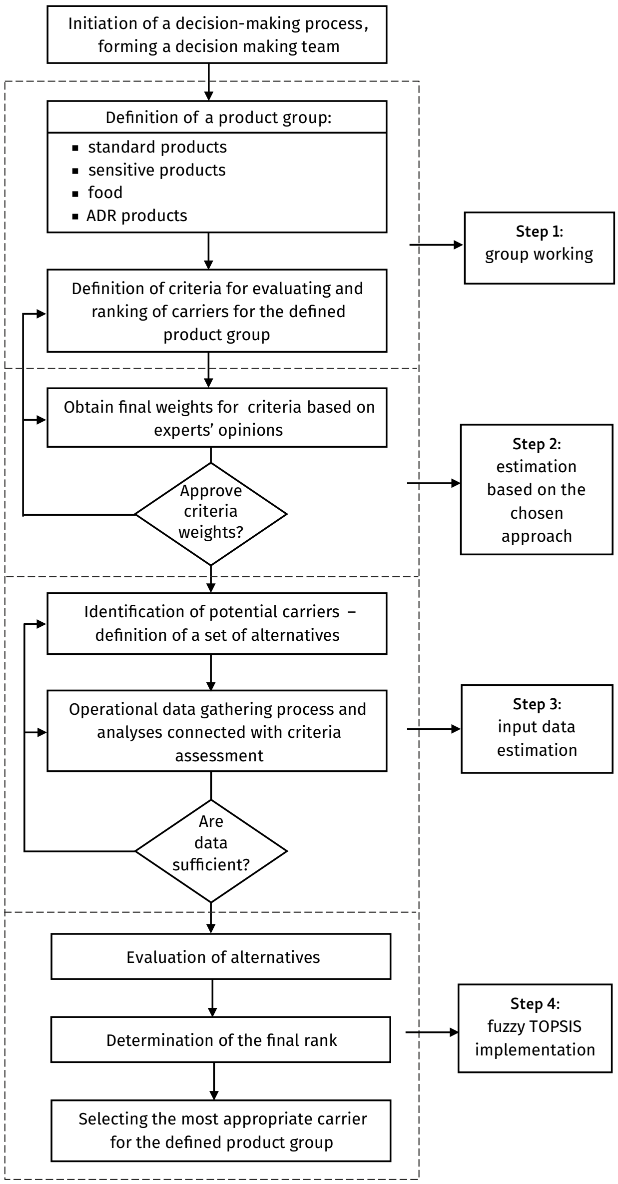

Figure 1. The scheme of framework for carrier selection process under uncertainty (source: own contribution)

3.1. Input parameters definition

The 1st step involves necessary input parameters definition. The process of carrier selection requires selection of the best alternative form M alternatives taking into account an N dimensional space of criterion that depends on L dimensional space of attributes. Based on the conducted literature review and survey research done in chosen transportation companies, the structure of the carrier selection problem may be represented by the Figure 2.

Following this, based on the problem structure given in the Figure 2, we should define the following input data:

- set of cargo groups G_l, where $G_l = \{G_1, G_2, \dots, G_L\}$;
- set of alternatives B_i^l, where $B_i^l = \{B_1^1, B_2^1, \dots, B_{M-1}^L, B_M^L\}$;
- set of criteria C_j^l that are assigned to the individual product groups G_l; $C_j^l = \{C_1^1, C_2^1, \dots, C_{N-1}^L, C_N^L\}$;
- assuming K amount of decision makers D_k, where $D_k = \{D_1, D_2, \dots, D_K\}$.

The alternatives B_i^l regard to the possible logistic handling operators that provide the necessary transportation services for the chosen groups of products. The cargo groups, i.e. individual product groups were described in detail in the Section 2. The defined cargo groups have a direct impact on the type of criteria that will be assessed during carrier selection. The selection criteria are defined in the Table 2.

The last important issue in this stage of the carrier selection procedure is the assessment of criteria weights.

Let $W_j^l = \left[w_1^l, w_2^l, \dots, w_N^l\right]$ be the vector of criteria weights for a given individual product group G_l. Based on the available literature, this vector for every cargo group may be evaluated based on one of the 3 main approaches implementation.

First approach. The criteria weights are expressed precisely by real numbers (crisp data), when satisfying the following assumption:

$$\sum_{j=1}^{N} w_j^l = 1. \tag{1}$$

Second approach. The criteria weights may be also expressed by a vector of linguistic values. In this approach we define the scale of linguistic terms. Thus, usually there are used expressions to give the evaluation value of chosen criteria by 7 linguistic terms, from "very big" to "very small" with respect to 7 fuzzy scale (Table 3). Following this, the larger weight is given to the criterion, the greater importance is given to that criterion for carrier selection.

The scale of linguistic terms may be also presented with the use of trapezoidal FN (e.g., Nădăban *et al.* (2016); Rudnik, Kacprzak (2017)).

Third approach. The last method of criteria weights estimation bases on AHP method implementation. Due to the uncertain environment implementation in carrier selection process, the fuzzy APH method should be used in order to find fuzzy preference weights (Rudnik, Kacprzak 2017; Sun 2010). The AHP method was developed by Saaty in 1980 (based on (Nădăban *et al.* 2016)). The fuzzy theory was incorporated into AHP method by Buckley (1985). The procedure for fuzzy AHP implementation into criteria weight evaluation is presented, e.g., in works by Nădăban *et al.* (2016) and Sun (2010). This procedure bases on 2 main steps:

- construct fuzzy pairwise comparison matrices based on decision makers opinion;
- compute the fuzzy weights by normalization.

Table 3. Linguistic term for weights of criteria (Zheng 2015)

Linguistic terms	Scale of FN (based on TFN use)
Very big (VB)	(0.9, 1, 1)
Fairly big (FB)	(0.7, 0.9, 1)
Big (B)	(0.5, 0.7, 0.9)
Middle (M)	(0.3, 0.5, 0.7)
Small (S)	(0.1, 0.3, 0.5)
Fairly small (FS)	(0, 0.1, 0.3)
Very small (VS)	(0, 0, 0.1)

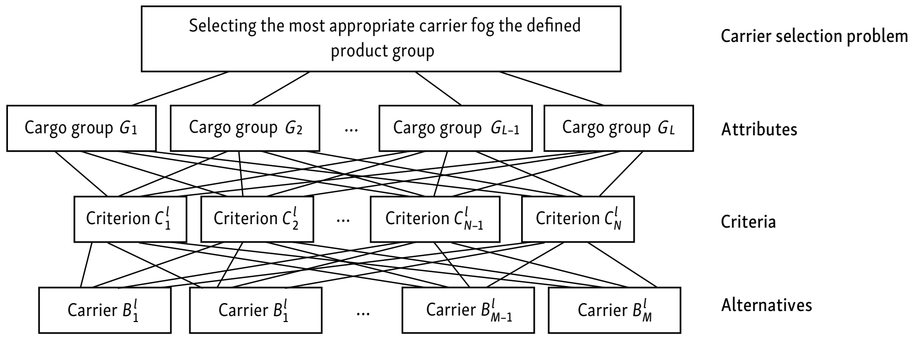

Figure 2. Structure of carrier selection problem (source: own contribution)

The chosen approach mainly influences the method of computing the aggregated fuzzy ratings for criteria weights (Awasthi *et al.* 2011; Nădăban *et al.* 2016).

3.2. Fuzzy TOPSIS implementation in selection of the best alternative

The fuzzy TOPSIS technique was 1st published by Hwang and Yoon in 1981 – according to Nădăban *et al.* (2016). This method is based on the principles that the chosen alternative is the closest to the PIS and the farthest from the NIS (Rudnik, Kacprzak 2017; Zheng 2015). In the analysed carrier selection problem, when searching the best solution we base on the triangular FN implementation.

A triangular FN is presented by a triplet $A_z = (a, b, c)$, and its member function is given by:

$$\mu_z(x) = \begin{cases} \dfrac{x-a}{b-a}, & \text{for } a \le x \le b; \\ \dfrac{c-x}{c-b}, & \text{for } b \le x \le c. \end{cases} \quad (2)$$

The FN parameters meaning is straightforward: a and c are the lower and upper bounds of FN A_z, respectively, and b denotes the modal value of FN A_z.

In the given approach, the TFN are used to represent linguistic variables for evaluation of alternatives with respect to each criterion. The representation is presented in Table 4.

Moreover, the distance between the 2 triangular FNs is calculated based on a vertex method (Chen 2000). If we have 2 FN: $A_{z1} = (a_1, b_1, c_1)$ and $A_{z2} = (a_2, b_2, c_2)$, the distance between them is calculated based on the following equation:

Table 4. Linguistic variables for the evaluation of alternatives (Rudnik, Kacprzak 2017))

Linguistic terms	Scale of FN (based on TFN use)
Very good (VG)	(8, 9, 10)
Good (G)	(7, 9, 10)
Medium good (MG)	(5, 7, 9)
Fair (F)	(3, 5, 7)
Medium poor (MP)	(1, 3, 5)
Poor (P)	(0, 1, 3)
Very poor (VP)	(0, 0, 1)

$$d\left(A_{z1}, A_{z2}\right) = \sqrt{\frac{1}{3}\cdot\left(\left(a_1-a_2\right)^2+\left(b_1-b_2\right)^2+\left(c_1-c_2\right)^2\right)}. \quad (3)$$

The procedure of fuzzy TOPSIS with CFN consists of 7 main steps and is presented below (Awasthi *et al.* 2011; Rudnik, Kacprzak 2017).

Step 1. Define the fuzzy decision matrix $X_G(l)$ for alternatives with respect to criteria and product groups.

Let's assume that the rating of alternative B_i^l, where i = (1, 2, 3, ..., M), with respect to criterion C_j^l for the given individual product group G_l is denoted by $x_{ij}^l = \left(a_{ij}^l, b_{ij}^l, c_{ij}^l\right)$. Thus, the decision matrix for the given individual product group G_l, where l = (1, 2, 3, ..., L), is given as:

$$X_G(l) = \begin{array}{c} \\ B_1^l \\ B_2^l \\ \vdots \\ B_M^l \end{array} \begin{array}{c} \begin{array}{cccc} C_1^l & C_2^l & \cdots & C_N^l \end{array} \\ \begin{bmatrix} x_{11}^l & x_{12}^l & \cdots & x_{1N}^l \\ x_{21}^l & x_{22}^l & \cdots & x_{2N}^l \\ \vdots & \vdots & \ddots & \cdots \\ x_{M1}^l & x_{M2}^l & \cdots & x_{MN}^l \end{bmatrix} \end{array}, \quad (4)$$

where: l = (1, 2, 3, ..., L).

The ratings x_{ij}^l are aggregated fuzzy ratings evaluated by every expert D_k, where k = (1, 2, 3, ..., K), based on the expression:

$$x_{ij}^l = \frac{1}{K}\cdot\left(x_{ij1}^l \oplus \ldots \oplus x_{ijk}^l \oplus \ldots \oplus x_{ijK}^l\right) \quad (5)$$

and:

$$x_{ijk}^l = \left(a_{ijk}^l, b_{ijk}^l, c_{ijk}^l\right), \quad (6)$$

where: $\oplus$ – the function of addition of the FNs.

Step 2. Construct the normalized fuzzy decision matrix $R_G(l)$ using linear normalization.

The normalized fuzzy decision matrix for the given individual product group G_l, where l = (1, 2, 3, ..., L), is given as:

$$R_G(l) = \left(r_{ij}^l\right)_{M\times N}, \quad (7)$$

where: l = (1, 2, 3, ..., L).

Where the normalized fuzzy ratings can be obtained by following equation:

$$r_{ij}^l = \begin{cases} \dfrac{a_{ij}^l}{\max\limits_i c_{ij}^l}, \dfrac{b_{ij}^l}{\max\limits_i c_{ij}^l}, \dfrac{c_{ij}^l}{\max\limits_i c_{ij}^l}, & \text{if } j \in C_b^l; \\ \dfrac{\min\limits_i a_{ij}^l}{a_{ij}^l}, \dfrac{\min\limits_i a_{ij}^l}{b_{ij}^l}, \dfrac{\min\limits_i a_{ij}^l}{c_{ij}^l}, & \text{if } j \in C_c^l, \end{cases} \quad (8)$$

where: C_b^l is the set of benefit criteria for a given cargo group G_l; C_c^l is the set of cost criteria for a given cargo group G_l.

After the normalization, the fuzzy rating r_{ij}^l is still a TFN.

Step 3. Construct the weighted normalized fuzzy decision matrix $V_G(l)$.

The weighted normalized fuzzy decision matrix $V_G(l)$ is obtained by multiplying the columns of the normalized fuzzy decision matrix $R_G(l)$ by the associated weights w_j^l for each criterion obtained for a given cargo group G_l:

$$V_G\left(l\right)=\left(v_{ij}^l\right)_{M\times N}, \tag{9}$$

where: l = (1, 2, 3, ..., L).
and v_{ij}^l can be calculated as:

$$v_{ij}^l=\begin{cases} r_{ij}^l\cdot w_j^l, & \text{if } w_j^l \text{ is a real number;} \\ r_{ij}^l\otimes w_j^l, & \text{if } w_j^l \text{ is a fuzzy number,} \end{cases} \tag{10}$$

where: $\otimes$ – the function of multiplication of the FNs.

Step 4. Determine the fuzzy PIS and fuzzy NIS for the given individual product group G_l, where l = (1, 2, 3, ..., L).

At this stage of the procedure we can define the fuzzy PIS A^{l+} (aspiration levels) and fuzzy NIS A^{l-} (the worst levels).

The fuzzy PIS or a given individual group of products is given as:

$$A^{l+}=\left(v_1^{l+}, v_2^{l+}, \ldots, v_N^{l+}\right), \tag{11}$$

where, for j = 1, 2, ..., N we obtain:

$$v_j^{l+}=\max_i v_{ij}^l=\left(\max_i a_{ij}^l, \max_i b_{ij}^l, \max_i c_{ij}^l\right). \tag{12}$$

The fuzzy NIS is given as:

$$A^{l-}=\left(v_1^{l-}, v_2^{l-}, \ldots, v_N^{l-}\right), \tag{13}$$

where, for j = 1, 2, ..., N we obtain:

$$v_j^{l-}=\min_i v_{ij}^l=\left(\min_i a_{ij}^l, \min_i b_{ij}^l, \min_i c_{ij}^l\right). \tag{14}$$

Step 5. Calculate the distance of each alternative from fuzzy PIS and fuzzy NIS.

The distances d_i^{l+} and d_i^{l-} of each alternative from A^{l+} and A^{l-} can be calculated by the area compensation method:

$$\begin{cases} d_i^{l+}=\sum_{j=1}^{N} d\left(v_{ij}^l, v_j^{l+}\right); \\ d_i^{l-}=\sum_{j=1}^{N} d\left(v_{ij}^l, v_j^{l-}\right), \end{cases} \tag{15}$$

where, the distance d between 2 FNs is calculated according to the Equation (3).

Step 6. Calculate the relative closeness of each alternative to the ideal solutions A^{l+} and A^{l-}.

The relative closeness of each alternative to the ideal solutions for the given individual group of products can be calculated with the equation:

$$RC_i^l=\frac{d_i^{l-}}{d_i^{l+}+d_i^{l-}}=1-\frac{d_i^{l+}}{d_i^{l+}+d_i^{l-}}. \tag{16}$$

Step 7. Rank the alternatives and choose the best option.

During this step the alternatives B_i^l, where i = (1, 2, 3, ..., M), should be ranked according to the value of RC_i^l indicator. According to this, the decision maker should select this carrier with the largest value of evaluated indicator.

The next section presents the application of the given framework in the selected transport company.

4. Case study

The surveyed logistics operator has been providing its services for over 20 years. It is an organization with Polish capital, for which reliability, professionalism, and customer orientation are the main values of organizational culture. The offer directed to the market includes road, sea and air transport services as well as contract logistics, including warehouse operations related to the distribution of products. However, the largest share in both, revenues and costs, is associated with the provision of road transport services. Road transport refers to the transport of LCL and FCL goods. At present, the company applies a classic scheme of carrier for cargo transportation selection.

The company's own fleet constitutes a small share of vehicles servicing transport orders. They are directed primarily at handling FCL goods and regular transports carried out as part of strategic projects operated by the logistic operator. The vast majority of orders are therefore handled using cooperating carriers. It should be noted, that the operator is focused on undertaking long-term cooperation with its subcontractors. Carriers cooperating with the analysed operator receive partner support, including, e.g., carrier liability insurance on special conditions, fleet cards for refuelling on favourable conditions, legal support, GPS monitoring. At the same time, carriers cooperating on a partnership basis are regularly audited by the operator in terms of, e.g., timeliness of deliveries, or pallets convertibility. The results of these assessments are published in the form of reports also available to subcontractors. Forwarders employed by the operator also cooperate with carriers offering their services via the freight exchanges. The most frequently used offers are from the 3 largest freight exchanges, namely: *TimoCom*, *Trans.eu* and *Teleroute*.

The purpose of the analysis is to compare the classic carrier selection method to handle a transport order with the proposed approach using the TOPSIS method and fuzzy sets. This comparison will apply to different groups of handled loads, taking into account their specific requirements. In order to emphasize the significance of the proposed approach, apart from standard loads (which do not have special transport requirements), other groups of cargo are taken into consideration: food loads and the so-called sensitive loads. Due to the specificity of transport service, the price criterion in their case loses their priority. In addition, the use of classic carrier selection methods in their case increases the risk of loss or damage to the transported load. Therefore, they should be subject to a broader analysis.

4.1. Definition of criteria and weights assessment for traditional approach to carrier selection

The audited company currently applies the traditional approach to the selection of the transport offer for load handling. In this approach, transport options are assessed on a 10-point scale. Ratings are assigned by the forwarder based on point assessment. The presented scoring is a mapping of the carrier selection system in one of the examined logistics operators.

The basic evaluation criterion is always the price. Points are allocated based on the following valuation (Table 5).

Secondly, there is assessed the insurance amount purchased by the carrier. In this case, the valuation of this criterion is as follows (Table 6).

The last assessment criterion, taken into account only for selected groups of transported loads is the number of certificates held by the carrier. The valuation of this criterion is similar to the previous defined one (Table 7).

The weights assigned to individual criteria in the traditional procedure are presented for 3 product groups (Table 8). The weights presented in the table are the applicable values in the examined case company.

In the new proposed approach to the assessment of transport options, the number of criteria taken into account has been enriched by an additional criterion – experience in cooperation with the operator determined by the OTIF indicator. This is an important criterion, especially for sensitive goods and ADR products. More and more logistics operators in their risk management procedures are introducing a new regulations connected with elimination of selection of accidental carriers for handling sensitive products. This is mainly due to the increasingly publicized cases of organized crime activities that specialize in the theft of this particular group of goods.

4.2. Definition of criteria and weights assessment for fuzzy approach to carrier selection

The evaluation of transport options offers in the proposed method is based on a valuation carried out using a scale based on fuzzy sets, described in a linguistic manner (Table 4). The linguistic approach will also be used to determine the weights for individual criteria according to the Table 3.

On the basis of interviews conducted with forwarders in the examined enterprise, the linguistic weights for the 3 main analysed product groups were determined and the results are presented in Table 9. In total, 24 forwarders took part in the evaluation process. The research based on the use of brainstorming technique.

Table 5. Point scale for price criterion evaluation (source: own contribution)

The highest offered price	Price above the average price level	Average price level	Price below the average price level	The lowest offered price
1	3	5	7	10

Table 6. Point scale for the insurance level evaluation (source: own contribution)

Basic insurance	Extended insurance	Full option of required insurance
1	5	10

Table 7. Point scale for the number of carrier's certificate evaluation (source: own contribution)

Lack of certificates	Part of required certificates (necessary/basic)	All required certificates
1	5	10

Table 8. Weights assigned to the individual product groups (source: own contribution)

Criterion	Cargo type		
	Standard products	Sensitive products	Food
Price C_1	0.9	0.6	0.7
The required amount of insurance C_2	0.1	0.3	0.2
Required certificates C_3	0	0.1	0.1

Table 9. Type of assessment parameters according to the individual product groups (source: own contribution)

Criterion	Weights for cargo types		
	Standard products	Sensitive products	Food
Price C_1	VB	B	FB
The required amount of insurance C_2	S	FB	B
Required certificates C_3	VS	S	VB
Required experience in cooperation with the operator with OTIF index C_4	S	FB	B

4.3. Carrier selection process based on traditional approach

The analysis is performed based on the chosen 4 offers of transport options (the same options for every product group), which are defined below:

- B_1 – own driver/own logistic operator;
- B_2 – external carrier with a signed contract;
- B_3 – external carrier cooperating periodically with logistic operator;
- B_4 – carrier obtained from the freight transport exchange, so far no cooperation performed.

Table 10 presents the results of the valuation of individual transport offers before taking into account the weights assigned to the criteria for individual product groups. The points were assigned by experts of the examined case company.

Table 11 presents the results of the evaluation obtained for each transport option, taking into account the weights applicable to individual groups of goods (Table 8).

The presented results of the conducted analysis in the traditional approach indicate the dominant role of the "price" criterion. For this reason, for all product groups, the assessment of transport options indicates that the best option is the selection of the B_4 supplier, i.e. the carrier from the fright transport exchange. This is in contradiction with the rules increasingly introduced by operators that recommend limiting the risk of possible losses resulting from ordering the transport of selected groups of loads to unknown carriers. At the same time, it should be noted that the current assessment system does not allow for full differentiation of the allocated values, in particular when the number of analysed offers (options) is greater than 5, which often happens for logistic operator case. This means that the shipper must assign the same rating to 2 different offers, which may lead to the wrong decision-making. For this reason, it is reasonable to propose a new approach to the assessment of transport options, using the concept of fuzzy sets.

Table 10. Assessment of offers of transport options with the use of point method (source: own contribution)

Criterion	Alternative			
	B_1	B_2	B_3	B_4
C_1	1	3	5	10
C_2	10	10	5	1
C_3	10	10	5	1
C_4	–	–	–	–

4.4. Carrier selection process based on fuzzy TOPSIS approach

In order to have the possibility to compare the obtained results of carrier selection processes, in both cases (traditional and proposed), analogous parameters of the submitted offers are assumed. In the 1st step, the evaluation of the offers is purely linguistic (Table 12). The assessments were made by forwarders participating in the conducted research.

Based on the given assessment of the transport options offers, there can be implemented the main steps of fuzzy TOPSIS approach. Thus, at the beginning the fuzzy decision matrix $X_G(l)$ for alternatives with respect to criteria and product groups and based on the Table 4 is assessed (Table 13). Each alternative B_i for the given criterion C_i is estimated as FN $x_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right)$. The criterion evaluation ("cost" criterion / "benefit" criterion) influences the direction of FNs. For the 1st 2 steps the product group G_l is omitted (the results are the same for the all analysed product groups – the difference lies in the estimated weights for product groups – thus the index l in the given variables is omitted).

With the use of Equation (8), the fuzzy decision matrix was normalized based on the criterion type ("cost"/"benefit"). For example, for the cost criterion C_1 normalization of alternative B_2 is given as:

$$r_{21} = \left(\frac{\min_i a_{i1}}{a_{21}}, \frac{\min_i a_{i1}}{a_{21}}, \frac{\min_i a_{i1}}{a_{21}}\right) =$$

$$\left(\frac{1}{1}, \frac{1}{3}, \frac{1}{5}\right) = \left(1, 0.33, 0.2\right).$$

Whereas, for the benefit criterion – e.g., C_2, the normalization for alternative B_1 is given as:

$$r_{12} = \left(\frac{a_{12}}{\max_i c_{12}}, \frac{b_{12}}{\max_i c_{12}}, \frac{c_{12}}{\max_i c_{12}}\right) =$$

$$\left(\frac{8}{10}, \frac{9}{10}, \frac{10}{10}\right) = \left(0.8, 0.9, 1\right)$$

All the normalized values were calculated according to the given above example. The obtained results are presented in the normalized fuzzy decision matrix $R_G(l)$, being presented in Table 14, where C_1 is a cost criterion (marked red) and criteria C_2 to C_4 are benefit criteria (marked yellow).

Next step is connected with construction of the weighted normalized fuzzy decision matrix $V_G(l)$. The results are obtained based on the estimated weights (Table 9)

Table 11. Assessment of offers of transport options with the use of weighted point method (source: own contribution)

Criterion	Offers of transport options according to cargo type (alternative)											
	Standard products				Sensitive products				Food			
	B_1	B_2	B_3	B_4	B_1	B_2	B_3	B_4	B_1	B_2	B_3	B_4
C_1	0.9	2.7	4.5	9	0.6	1.5	3.0	6.0	0.7	2.1	3.5	7.0
C_2	1.0	1.0	0.5	0.1	3.0	3.0	1.5	0.3	2.0	2.0	1.0	0.2
C_3	0.0	0.0	0.0	0.0	1.0	1.0	0.5	0.1	1.0	1.0	0.5	0.1
C_4	–	–	–	–	–	–	–	–	–	–	–	–
Sum	1.9	3.7	5.0	9.1	4.6	5.5	5.0	6.4	3.7	5.1	5.0	7.3

Table 12. Assessment of offers of transport options with the use of fuzzy TOPSIS approach (source: own contribution)

Criterion	Alternative			
	B_1	B_2	B_3	B_4
C_1	MP	MP	MG	VG
C_2	VG	G	F	F
C_3	VG	VG	MG	F
C_4	G	G	MP	VP

Table 13. The fuzzy decision matrix $X_G(l)$ (source: own contribution)

Alternative	Criterion			
	C_1	C_2	C_3	C_4
B_1	(1, 3, 5)	(8, 9, 10)	(8, 9, 10)	(7, 9, 10)
B_2	(1, 3, 5)	(7, 9, 10)	(8, 9, 10)	(7, 9, 10)
B_3	(5, 7, 9)	(3, 5, 7)	(5, 7, 9)	(1, 3, 5)
B_4	(8, 9, 10)	(3, 5, 7)	(3, 5, 7)	(0, 0, 1)

and Equations (9) and (10). Since both, the assessment of alternatives and the weights of criteria are described by fuzzy variables, the calculations were carried out in accordance with the equation for the product of 2 FNs (Kosiński, Prokopowicz 2004):

$$r_{ij}^{l} \otimes w_{j}^{l} = \left(\left(a_{ij}^{l}, b_{ij}^{l}, c_{ij}^{l}\right) \otimes (a_{wj}^{l}, b_{wj}^{l}, c_{wj}^{l}\right) = \left(a_{ij}^{l} a_{wj}^{l},\ a_{ij}^{l} b_{wj}^{l} + a_{wj}^{l} b_{ij}^{l} - b_{ij}^{l} b_{wj}^{l},\ a_{ij}^{l} c_{wj}^{l} + a_{wj}^{l} c_{ij}^{l} + c_{ij}^{l} c_{wj}^{l}\right)$$
$$\text{for } r_{ij}^{l} > 0 \text{ and } w_{j}^{l} > 0. \tag{17}$$

For example, for standard products the calculations for the cost criterion C_1^1 and alternative B_1^1 are estimated below:

$$r_{11}^{1} \otimes w_{1}^{1} = \left(\left(a_{11}^{1},\ b_{11}^{1},\ c_{11}^{1}\right) \otimes \left(a_{w1}^{1},\ b_{w1}^{1},\ c_{w1}^{1}\right)\right) = \left(1,\ 0.333, 0.2\right) \otimes \left(0.9,\ 1,\ 1\right) = \left(1 \cdot 0.9,\ 1 \cdot 1 + 0.9 \cdot 0.333 - 1 \cdot 0.333,\ 1 \cdot 1 + 0.9 \cdot 0.2 + 0.2 \cdot 1\right) = \left(0.9,\ 0.967,\ 1.38\right).$$

The obtained results from this step are presented in Tables 15–17, for each group of products separately.

The presented matrixes are used to determine the fuzzy PIS and fuzzy NIS for the given individual product group G_l, where l = (1, 2, 3, ..., L). At this stage of the procedure we can define the fuzzy PIS A^{l+} (aspiration levels) and fuzzy NIS A^{l-} (the worst levels) according to Equations (11)–(14):

$$A^{l+} = \left(v_1^{l+}, v_2^{l+}, \ldots,\ v_N^{l+}\right) = \left(\left(0.9, 0.967, 1.38\right), \left(0.08, 0.06, 1\right), \left(0, 0, 0.18\right), \left(0.07, 0.03, 0.95\right)\right)$$
for l = 1;
$$A^{l+} = \left(v_1^{l+}, v_2^{l+}, \ldots, v_N^{l+}\right) = \left(\left(0.5, 0.633, 1.18\right), \left(0.56, 0.54, 2.5\right), \left(0.08, 0.06, 1\right), \left(0.49, 0.45, 2.4\right)\right)$$
for l = 2;
$$A^{l+} = \left(v_1^{l+}, v_2^{l+}, \ldots, v_N^{l+}\right) = \left(\left(0.7, 0.833, 1.34\right), \left(0.4, 0.38, 2.12\right), 2.7, \left(0.35, 0.31, 2.03\right)\right)$$
for l = 3

and

$$A^{l-} = \left(v_1^{l-}, v_2^{l-}, \ldots, v_N^{l-}\right) = \left(\left(0.113, 0.114, 0.315\right), \left(0.03, 0, 0.57\right), \left(0, 0, 0.1\right), \left(0, 0, 0.06\right)\right)$$
for l = 1;
$$A^{l-} = \left(v_1^{l-}, v_2^{l-}, \ldots, v_N^{l-}\right) = \left(\left(0.063, 0.065, 0.253\right), \left(0.21, 0.17, 1.49\right), \left(0.03, 0, 0.57\right), \left(0, 0, 0.17\right)\right)$$
for l = 2;
$$A^{l-} = \left(v_1^{l-}, v_2^{l-}, \ldots, v_N^{l-}\right) = \left(\left(0.088, 0.09, 0.295\right), \left(0.15, 0.11, 1.25\right), \left(0.27, 0.25, 1.63\right), \left(0, 0, 0.14\right)\right)$$
for l = 3.

A weighted, fuzzyfied and normalized rating for each criterion was compared with fuzzy PIS and fuzzy NIS for the given individual product group G_l, where l = (1, 2, 3, ..., L). The calculations based on the distances d_i^{l+} and d_i^{l-} (Equations (15) and (3)). Later, the relative closeness of each alternative to the ideal solutions for the given individual group of products was calculated based on Equation (16). The example of calculations for distances d_i^{l+} and d_i^{l-} of alternative B_3^1 from A^{l+} and A^{l-} for standard product group is given below.

The distance from the ideal solution for a:

$$d_3^{l+} = \sum_{j=1}^{4} d\left(v_{3j}^{l}, v_j^{l+}\right) = \sqrt{\frac{1}{3} \cdot \left(\left(0.18 - 0.9\right)^2 + \left(0.186 - 0.967\right)^2 + \left(0.411 - 1.38\right)^2\right)} + \ldots + \sqrt{\frac{1}{3} \cdot \left(\left(0.01 - 0.07\right)^2 + \left(0 - 0.03\right)^2 + \left(0.35 - 0.95\right)^2\right)} =$$
$$1.019 + 1.094 + 0.217 + 1.529 = 3.859.$$

And the distance from the anti-ideal solution:

$$d_3^{l-} = \sum_{j=1}^{4} d\left(v_{3j}^{l}, v_j^{l-}\right) = \sqrt{\frac{1}{3} \cdot \left(\left(0.18 - 0.113\right)^2 + \left(0.186 - 0.114\right)^2 + \left(0.411 - 0.315\right)^2\right)} + \ldots + \sqrt{\frac{1}{3} \cdot \left(\left(0.01 - 0\right)^2 + \left(0 - 0\right)^2 + \left(0.35 - 0.06\right)^2\right)} =$$
$$0.126 + 0 + 0.04 + 0{,}29 = 0.456.$$

Following this, then the final value of RC_i^l indicator of the alternative assessment is given:

$$RC_3^l = \frac{d_3^{l-}}{d_3^{l+} + d_3^{l-}} = \frac{0.456}{3.859 + 0.456} = 0.16.$$

The calculated final values of RC_i^l indicator for the rest alternatives and for all the product groups are given in Tables 18–20.

Table 14. The normalized fuzzy decision matrix $R_G(l)$ (source: own contribution)

Alternative	Criterion											
	C_1			C_2			C_3			C_4		
	a_{i1}	b_{i1}	c_{i1}	a_{i2}	b_{i2}	c_{i2}	a_{i3}	b_{i3}	c_{i3}	a_{i4}	b_{i4}	c_{i4}
B_1	1.000	0.333	0.200	0.8	0.9	1.0	0.8	0.9	1.0	0.7	0.9	1.0
B_2	1.000	0.333	0.200	0.7	0.9	1.0	0.8	0.9	1.0	0.7	0.9	1.0
B_3	0.200	0.143	0.111	0.3	0.5	0.7	0.5	0.7	0.9	0.1	0.3	0.5
B_4	0.125	0.111	0.100	0.3	0.5	0.7	0.3	0.5	0.7	0.0	0.0	0.1

Table 15. The weighted normalized fuzzy decision matrix $V_G(l)$ for standard products (l = 1) (source: own contribution)

Alternative	Criterion											
	C_1			C_2			C_3			C_4		
	a_{i1}	b_{i1}	c_{i1}	a_{i2}	b_{i2}	c_{i2}	a_{i3}	b_{i3}	c_{i3}	a_{i4}	b_{i4}	c_{i4}
B_1	0.900	0.967	1.380	0.08	0,06	1.00	0.0	0.0	0.18	0.07	0.03	0.95
B_2	0.900	0.967	1.380	0.07	0.03	0.95	0.0	0.0	0.18	0.07	0.03	0.95
B_3	0.180	0.186	0.411	0.03	0.00	0.57	0.0	0.0	0.14	0.01	0.00	0.35
B_4	0.113	0.114	0.315	0.03	0.00	0.57	0.0	0.0	0.10	0.00	0.00	0.06

Table 16. The weighted normalized fuzzy decision matrix $V_G(l)$ for sensitive products (l = 2) (source: own contribution)

Alternative	Criterion											
	C_1			C_2			C_3			C_4		
	a_{i1}	b_{i1}	c_{i1}	a_{i2}	b_{i2}	c_{i2}	a_{i3}	b_{i3}	c_{i3}	a_{i4}	b_{i4}	c_{i4}
B_1	0.500	0.633	1.180	0.56	0.54	2.50	0.08	0.06	1.00	0.49	0.45	2.40
B_2	0.500	0.633	1.180	0.49	0.45	2.40	0.08	0.06	1.00	0.49	0.45	2.40
B_3	0.100	0.111	0.336	0.21	0.17	1.49	0.05	0.01	0.79	0.07	0.03	0.95
B_4	0.063	0.065	0.253	0.21	0.17	1.49	0.03	0.00	0.57	0.00	0.00	0.17

Table 17. The weighted normalized fuzzy decision matrix $V_G(l)$ for food (l = 3) (source: own contribution)

Alternative	Criterion											
	C_1			C_2			C_3			C_4		
	a_{i1}	b_{i1}	c_{i1}	a_{i2}	b_{i2}	c_{i2}	a_{i3}	b_{i3}	c_{i3}	a_{i4}	b_{i4}	c_{i4}
B_1	0.700	0.833	1.340	0.40	0.38	2.12	0.72	0.71	2.70	0.35	0.31	2.03
B_2	0.700	0.833	1.340	0.35	0.31	2.03	0.72	0.71	2.70	0.35	0.31	2.03
B_3	0.140	0.151	0.389	0.15	0.11	1.25	0.45	0.43	2.21	0.05	0.01	0.79
B_4	0.088	0.09	0.295	0.15	0.11	1.25	0.27	0.25	1.63	0.00	0.00	0.14

Table 18. The distances from the ideal and anti-ideal solutions with calculated rank indicator for standard products (l = 1) (source: own contribution)

Alternative	$d\left(v_{ij}^{l}, v_j^{l+}\right)$				$d\left(v_{ij}^{l}, v_j^{l-}\right)$				d_i^{l+}	d_i^{l-}	RC_i^l	Rank
	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4				
B_1	0.000	0.000	0.00	0.000	1.438	0.435	0.080	0.891	0.000	2.845	1.00	1
B_2	0.000	0.059	0.00	0.000	1.438	0.382	0.080	0.891	0.059	2.791	0.979	2
B_3	1.312	0.435	0.04	0.602	0.126	0.000	0.040	0.290	2.389	0.456	0.160	3
B_4	1.438	0.435	0.08	0.891	0.000	0.000	0.000	0.000	2.845	0.000	0.000	4

Table 19. The distances from the ideal and anti-ideal solutions with calculated rank indicator for sensitive products (l = 2) (source: own contribution)

Alternative	$d\left(v_{ij}^{l}, v_j^{l+}\right)$				$d\left(v_{ij}^{l}, v_j^{l-}\right)$				d_i^{l+}	d_i^{l-}	RC_i^l	Rank
	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4				
B_1	0.000	0.000	0.000	0.000	1.117	1.094	0.435	2.292	0.000	4.939	1.000	1
B_2	0.000	0.000	0.000	0.000	1.117	0.966	0.435	2.292	0.140	4.810	0.972	2
B_3	1.019	1.094	0.217	1.529	0.097	0.000	0.221	0.782	3.859	1.100	0.222	3
B_4	1.117	1.094	0.435	2.292	0.000	0.000	0.000	0.000	4.939	0.000	0.000	4

Table 20. The distances from the ideal and anti-ideal solutions with calculated rank indicator for food (l = 3) (source: own contribution)

Alternative	$d\left(v_{ij}^{l}, v_{j}^{l+}\right)$				$d\left(v_{ij}^{l}, v_{j}^{l-}\right)$				d_i^{l+}	d_i^{l-}	RC_i^l	Rank
	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4				
B_1	0.000	0.000	1.700	0.000	1.330	0.922	1.193	1.926	1.700	5.372	0.760	1
B_2	0.000	0.118	1.700	0.000	1.330	0.813	1.193	1.926	1.818	5.263	0.743	2
B_3	1.214	0.922	1.252	1.287	0.116	0.00	0.616	0.651	4.676	1.383	0.228	3
B_4	1.330	0.922	0.822	1.926	0.000	0.000	0.000	0.000	5.00	0.000	0.000	4

For the case when the proposed approach to carrier selection is based on the TOPSIS method, the "price" criterion is no longer as dominant as in the case of the classical approach use. For this reason, the B_4 supplier, despite having the lowest price offer, is tipped last in the carrier selection process. This is mainly connected with 2 elements: (1) this carrier obtained low value of the other parameters taken into account in the selection process; (2) the proposed approach broadened the scope of standard assessment criteria. In addition to the price, required insurance and certificates, the previous cooperation with a given carrier was also taken into account during the selection process performance. Thanks to this, own drivers and carriers who previously cooperate with the logistics operator are promoted. This approach is in line with the concept of partnership in the supply chain and strengthening relationships through long-term cooperation. At the same time, by using the TOPSIS method in the proposed decision-making process, it was possible to modify the weights by adjusting their distribution for individual assessment parameters. Thanks to this, the strength of the dominant criterion in the classical approach was "weakened" even in the case of standard goods. It should be noted that for this group of loads, the linguistic value given by the "price" criterion refers to the maximum weight of VB. Despite this, the proposed approach indicates the choice of "safer", although more expensive transport options.

4.5. Comparative analysis of the traditional approach and the proposed TOPSIS approach

The presented case study clearly illustrates the significant differences that occur in the traditional and proposed approach to the selection of transport option by the logistics operator. The innovation of the proposed approach lies not only in changing the evaluation method and introducing an additional evaluation criterion. Moreover, it is also important to change the approach to assigning weights to individual criteria and the scope of accepted scoring. The main differences between the classic approach and the proposed fuzzy approach are presented in Table 21.

A comparative analysis of the results obtained in the classical approach and in the proposed fuzzy approach based on the TOPSIS method (Table 22) indicates a significant change in the assumptions for the evaluation of alternatives (carriers' offers). Strong emphasis on the "price" criterion dominating in the classic approach means that in each of the analysed groups of loads, the B_4 supplier is

Table 21. Comparison of the traditional approach and the proposed fuzzy TOPSIS approach

	Traditional approach	Fuzzy approach
Number of criteria	3 criteria	4 criteria
Weight assignment	the most important criterion is price, the other criteria result from legal requirements for selected product groups, and their impact on the assessment is non-significant	weighting of the criteria is highly variable depending on the product group and the risk inherent in their handling process
Assessment method	scoring	fuzzy linguistic
Scoring method	simple, standardized point scale	taking into account the diversity of the offer in the same range of the assessed criterion

Table 22. Comparison of the obtained results for carrier selection based on classical method and the proposed fuzzy TOPSIS approach (source: own contribution)

Alternative	Standard products		Sensitive products		Food	
	Weighted method	Fuzzy TOPSIS	Weighted method	Fuzzy TOPSIS	Weighted method	Fuzzy TOPSIS
	Rank	Rank	Rank	Rank	Rank	Rank
B_1	4	1	4	1	4	1
B_2	3	2	2	2	2	2
B_3	2	3	3	3	3	3
B_4	1	4	1	4	1	4

selected as the best option, despite the limitations in providing the required certificates and insurances. This result is the effect of the dominant role played by criterion C_1. This approach may be beneficial for standard goods for which there are no specific guidelines for carrying out the transport. However, for other groups of products, this approach carries certain types of hazards. In the case of food products, the required certificates and appropriate insurance (including, e.g., intrusion by third parties into the semi-trailer) are significantly important. These criteria should therefore be given greater weight than in the classical approach. Similar conditions apply to sensitive goods. For these loads, the risk of theft related to transport increases significantly. Lack of adequate insurance for the carrier may be critical in consequences for both, the carrier himself and the logistics operator, who orders the transport.

The proposed approach to carrier evaluation, which bases on the TOPSIS method implementation, can be considered as a concept consistent with the frame of risk management in the supply chains. By introducing the 4th selection criterion, the proposed approach promotes carriers with whom the operator establishes (or has already established) strong business relationships. Due to the inclusion of the OTIF indicator in the evaluation of alternatives, having so far positive business experiences favour making safe choices. At the same time, this approach reduces the risk of adverse events arising from outsourcing of freight services to carriers that have not been verified or have been negatively verified by the logistics operator.

Thanks to the use of the TOPSIS method in the ranking of offers, the emphasis on individual selection criteria has also been changed. This additionally strengthens the effect of reducing the risk of adverse events occurrence, because the "price" criterion, even in the case of high rank (weight), does not dominate the selection process. This is especially important in the case of loads, in which the specificity of the transported goods or environmental conditions require consideration of the significance of the other assessment criteria.

Conclusions

In the presented work, we have proposed a fuzzy TOPSIS model for selection of the best logistic handling operator under uncertain (fuzzy) environment and taking into account the type of transported products as the main attribute. The proposed fuzzy approach is more adapted to current market requirements. Currently, logistics operators have to include a risk-based approach in their decision-making processes. Safety of a transported load and high requirements for the level of logistics service offered, expressed by the OTIF indicator, mean that managers should modify the currently operating traditional procedures. Only in this way will they be seen as a reliable partner for the developing logistics chains they support.

Following this, the presented comparison of both the analysed methods clearly state that the traditional approach is too limited in order to provide carrier selection process performance satisfying safety and reliability requirements of transport process performance. The new approach adheres to the market operational requirements and is simply applicable.

The presented research results are the part of conducted by the authors analyses on the concept of creating safe and resilient supply chains. Transport, as a link connecting individual participants of the supply chain, plays a significant role in the material flow process performance within the logistics network. It is also one of the most sensitive logistics processes implemented within the global network of connections due to the fact, that its implementation takes place at the interface of cooperating organizations and with using external infrastructure. Thus, it is a process that is particularly vulnerable to the occurrence of adverse events, on which a logistics operator has a limited impact. Further research conducted by the authors will be focused on other tools supporting risk management in supply chains. This risk will be analysed not only within transport, but also in the other stages of processing the finished product and its delivery to the consumer within the whole logistic chain.

Author contributions

Agnieszka Tubis – 50% (developing an analysis of modelling approach, case study preparation, drawing conclusions).

Sylwia Werbińska-Wojciechowska – 50% (developing the concept and plan for the preparation of the article, preparation of literature review, carrying out research in the modelled area, editing text and graphics).

Disclosure statement

Authors declare that they have no competing financial, professional, or personal interests from other parties that might have influenced the performance or presentation of the work described in this manuscript.

References

Abdullah, L.; Adawiyah, C. W. R. 2014. Simple Additive Weighting methods of multi criteria decision-making and applications: a decade review, *International Journal of Information Processing and Management* 5(1): 39–49.

Amoozad Mahdiraji, H.; Beheshti, M.; Razavi Hajiagha, S. H.; Zavadskas, E. K. 2018. A fuzzy binary bi objective transportation model: Iranian steel supply network, *Transport* 33(3): 810–820. https://doi.org/10.3846/transport.2018.5800

Anthony, P.; Behnoee, B.; Hassanpour, M.; Pamucar, D. 2019. Financial performance evaluation of seven Indian chemical companies, *Decision-making: Applications in Management and Engineering* 2(2): 81–99.

Antucheviciene, J.; Kala, Z.; Marzouk, M.; Vaidogas, E. R. 2015. Solving civil engineering problems by means of fuzzy and stochastic MCDM methods: current state and future research, *Mathematical Problems in Engineering* 2015: 362579. https://doi.org/10.1155/2015/362579

Asemi, Ad.; Bin Baba, M. S.; Asemi. As.; Haji Abdullah, R. B.; Idris, N. 2014. Fuzzy multi criteria decision-making applications: a review study, in *Proceedings of the 3rd International Conference on Computer Engineering* & *Mathematical Sciences* (*ICCEMS 2014*), 4–5 December 2014, Langkawi, Malaysia, 344–351.

Awasthi, A.; Chauhan, S. S.; Omrani, H. 2011. Application of fuzzy TOPSIS in evaluating sustainable transportation systems, *Expert Systems with Applications* 38(10): 12270–12280. https://doi.org/10.1016/j.eswa.2011.04.005

Baker, G. H. 1984. The carrier elimination decision: implications for motor carrier marketing, *Transportation Journal* 24(1): 20–29. Available from Internet: https://www.jstor.org/stable/20712793

Behzadian, M.; Kazemzadeh, R. B.; Albadvi, A.; Aghdasi, M. 2010. PROMETHEE: a comprehensive literature review on methodologies and applications, *European Journal of Operational Research* 200(1): 198–215. https://doi.org/10.1016/j.ejor.2009.01.021

Behzadian, M.; Khanmohammadi Otaghsara, S.; Yazdani, M.; Ignatius, J. 2012. A state-of the-art survey of TOPSIS applications, *Expert Systems with Applications* 39(17): 13051–13069. https://doi.org/10.1016/j.eswa.2012.05.056

Buckley, J. J. 1985. Fuzzy hierarchical analysis, *Fuzzy Sets and Systems* 17(3): 233–247. https://doi.org/10.1016/0165-0114(85)90090-9

Cadena, P. C. B.; Magro, J. M. V. 2015. Setting the weights of sustainability criteria for the appraisal of transport projects, *Transport* 30(3): 298–306. https://doi.org/10.3846/16484142.2015.1086890

Carlsson, C.; Fullér, R. 1996. Fuzzy multiple criteria decision-making: recent developments, *Fuzzy Sets and Systems* 78(2): 139–153. https://doi.org/10.1016/0165-0114(95)00165-4

Celik, E.; Gul, M.; Yucesan, M.; Mete, S. 2019. Stochastic multi-criteria decision-making: an overview to methods and applications, *Beni-Suef University Journal of Basic and Applied Sciences* 8: 4. https://doi.org/10.1186/s43088-019-0005-0

Chaghooshi, A. J.; Hajimaghsoudi, M. 2014. Reducing the risk of transportation disruption in supply chain: integration of fuzzy-AHP and TOPSIS, *Global Journal of Management Studies and Researches* 1(1): 1–9. Available from Internet: https://academicjournalscenter.org/index.php/GJMSR/article/download/8/pdf_6

Charnes, A.; Cooper, W. W.; Rhodes, E. 1978. Measuring the efficiency of decision-making units, *European Journal of Operational Research* 2(6): 429–444. https://doi.org/10.1016/0377-2217(78)90138-8

Chatterjee, P.; Stević, Ž. 2019. A two-phase fuzzy AHP – fuzzy TOPSIS model for supplier evaluation in manufacturing environment, *Operational Research in Engineering Sciences: Theory and Applications* 2(1): 72–90.

Chen, C.-T. 2000. Extensions of the TOPSIS for group decision-making under fuzzy environment, *Fuzzy Sets and Systems* 114(1): 1–9. https://doi.org/10.1016/S0165-0114(97)00377-1

Coyle, J. J.; Bardi, E. J.; Langley, C. J. 2003. *Management of Business Logistics: a Supply Chain Perspective*. 7th edition. South-Western College Pub. 707 p.

Dymova, L.; Sevastjanov, P.; Tikhonenko, A. 2013. An approach to generalization of fuzzy TOPSIS method, *Information Sciences* 238: 149–162. https://doi.org/10.1016/j.ins.2013.02.049

EC. 2007. *The EU's Freight Transport Agenda: Boosting the Efficiency, Integration and Sustainability of Freight Transport in Europe*. Communication from the Commission. 18.10.2007, COM(2007), 606 Final. European Commission (EC), Brussels, Belgium. 7 p. Available from Internet: https://eur-lex.europa.eu/LexUriServ.do?uri=COM:2007:0606:FIN:EN:PDF

Edwards, W.; Barron, F. H. 1994. SMARTS and SMARTER: improved simple methods for multiattribute utility measurement, *Organizational Behavior and Human Decision Processes* 60(3): 306–325. https://doi.org/10.1006/obhd.1994.1087

El Yamani, O.; Mouncif, H.; Rida, M. 2014. A fuzzy TOPSIS approach for finding shortest path in multimodal transportation networks, *International Journal of Computing and Optimization* 1(2): 95–111. https://doi.org/10.12988/ijco.2014.4917

Figueira, J. R.; Greco, S.; Roy, B.; Słowiński, R. 2010. ELECTRE methods: main features and recent developments, *Applied Optimization* 103: 51–89. https://doi.org/10.1007/978-3-540-92828-7_3

Fishburn, P. C. 1967. Additive utilities with incomplete product sets: application to priorities and assignments, *Operations Research* 15(3): 537–542. https://doi.org/10.1287/opre.15.3.537

Fontela, E.; Gabus, A. 1976. *The DEMATEL Observer*. Institute, Geneva Research Center, Geneva, Switzerland.

ISO 22000:2018. *Food Safety Management Systems*.

Kabir, G.; Hasin, M. A. A. 2012. Comparative analysis of TOPSIS and fuzzy TOPSIS for the evaluation of travel website service quality, *International Journal for Quality Research* 6(3): 169–185. Available from Internet: http://www.ijqr.net/journal/v6-n3/1.pdf

Kacprzak, D. 2018. Przedziałowa metoda TOPSIS dla grupowego podejmowania decyzji, *Optimum. Economic Studies* (4): 256–273. (in Polish). https://doi.org/10.15290/oes.2018.04.94.19

Kacprzak, D.; Rudnik, K. 2016. Metoda AHP i rozmyta SAW oparta na skierowanych liczbach rozmytych w procesie wyboru trasy dostawy, in *XIX Konferencja "Innowacje w Zarządzaniu i Inżynierii Produkcji"*, 28 lutego – 1 marca 2016, Zakopane, Polska, 2: 71–84. (in Polish). Available from Internet: http://ptzp.org.pl/files/konferencje/kzz/artyk_pdf_2016/T2/t2_0071.pdf

Keršulienė, V.; Zavadskas, E. K.; Turskis, Z. 2010. Selection of rational dispute resolution method by applying new step-wise weight assessment ratio analysis (SWARA), *Journal of Business Economics and Management* 11(2): 243–258. https://doi.org/10.3846/jbem.2010.12

Kolios, A.; Mytilinou, V.; Lozano-Minguez, E.; Salonitis, K. 2016. A comparative study of multiple-criteria decision-making methods under stochastic inputs, *Energies* 9(7): 566. https://doi.org/10.3390/en9070566

Kosiński, W.; Prokopowicz, P. 2004. Algebra liczb rozmytych, *Matematyka Stosowana* (5): 37–63. (in Polish). Available from Internet: https://wydawnictwa.ptm.org.pl/index.php/matematyka-stosowana/article/view/1237

Lwesya, F.; Jaffu, R. 2017. Customer service quality management in public transport: the case of rail transport in Tanzania, *International Review* 3–4: 102–117. https://doi.org/10.5937/intrev1704102L

Mardani, A.; Jusoh, A.; Zavadskas, E. K. 2015. Fuzzy multiple criteria decision-making techniques and applications – two decades review from 1994 to 2014, *Expert Systems with Applications* 42(8): 4126–4148. https://doi.org/10.1016/j.eswa.2015.01.003

Mardani, A.; Nilashi, M.; Zakuan, N.; Loganathan, N.; Soheilirad, S.; Saman, M. Z. M; Ibrahim, O. 2017a. A systematic review and meta-analysis of SWARA and WASPAS methods: theory and applications with recent fuzzy developments, *Applied Soft Computing* 57: 265–292. https://doi.org/10.1016/j.asoc.2017.03.045

Mardani, A.; Zavadskas, E. K.; Streimikiene, D.; Jusoh, A.; Khoshnoudi, M. 2017b. A comprehensive review of data envelopment analysis (DEA) approach in energy efficiency, *Renewable and Sustainable Energy Reviews* 70: 1298–1322. https://doi.org/10.1016/j.rser.2016.12.030

Mardani, A.; Zavadskas, E. K.; Khalifah, Z.; Zakuan, N.; Jusoh, A.; Nor, K. M.; Khoshnoudi, M. 2017c. A review of multi-criteria decision-making applications to solve energy management problems: two decades from 1995 to 2015, *Renewable and Sustainable Energy Reviews* 71: 216–256. https://doi.org/10.1016/j.rser.2016.12.053

Mardani, A.; Zavadskas, E. K.; Govindan, K.; Amat Senin, A.; Jusoh, A. 2016a. VIKOR technique: a systematic review of the state of the art literature on methodologies and applications, *Sustainability* 8(1): 37. https://doi.org/10.3390/su8010037

Mardani, A.; Zavadskas, E.K.; Khalifah, Z.; Jusoh, A.; Md Nor, K. 2016b. Multiple criteria decision-making techniques in transportation systems: a systematic review of the state of the art literature, *Transport* 31(3): 359–385. https://doi.org/10.3846/16484142.2015.1121517

Meixell, M. J.; Norbis, M. 2008. A review of the transportation mode choice and carrier selection literature, *The International Journal of Logistics Management* 19(2): 183–211. https://doi.org/10.1108/09574090810895951

Miljković, B.; Žižović, M. R.; Petojević, A.; Damljanović, N. 2017. New weighted sum model, *Filomat* 31(10): 2991–2998. https://doi.org/10.2298/FIL1710991M

Miller, D. W.; Starr, M. K. 1969. *Executive Decisions and Operations Research*. 2nd edition. Prentice-Hall, Inc.

Mohammaditabar, D.; Teimoury, E. 2008. Integrated freight transportation carrier selection and network flow assignment: methodology and case study, *Journal of Applied Sciences* 8(17): 2928–2938. https://doi.org/10.3923/jas.2008.2928.2938

Nădăban, S.; Dzitac, S.; Dzitac, I. 2016. Fuzzy TOPSIS: a general view, *Procedia Computer Science* 91: 823–831. https://doi.org/10.1016/j.procs.2016.07.088

Olson, D. L. 1996. *Decision Aids for Selection Problems*. Springer. 194 p. https://doi.org/10.1007/978-1-4612-3982-6

Osorio Gómez, J. C.; Manotas Duque, D. F. 2019. Fuzzy QFD and TOPSIS for dispatching prioritization in maritime transportation considering operational risk, in J. García Alcaraz, L. Rivera Cadavid, R. González-Ramírez, G. Leal Jamil, M. G. Chong Chong (Eds.). *Best Practices in Manufacturing Processes*, 97–116. https://doi.org/10.1007/978-3-319-99190-0_5

Perlman, Y.; Raz, T.; Moshka, L. 2009. Key factors in selecting an international freight forwarding company, *The Open Transportation Journal* 3: 29–34. https://doi.org/10.2174/1874447800903010029

Podvezko, V.; Sivilevičius, H. 2013. The use of AHP and rank correlation methods for determining the significance of the interaction between the elements of a transport system having a strong influence on traffic safety, *Transport* 28(4): 389–403. https://doi.org/10.3846/16484142.2013.866980

Putra, D. W. T.; Punggara, A. A. 2018. Comparison analysis of simple additive weighting (SAW) and weighted product (WP) in decision support systems, *MATEC Web of Conferences* 215: 01003. https://doi.org/10.1051/matecconf/201821501003

Roberts, K. W. 2012. *Key Factors and Trends in Transportation Mode and Carrier Selection*. Chancellor's Honors Program Projects. University of Tennessee, Knoxville, TN, US. 58 p. Available from Internet: https://trace.tennessee.edu/utk_chanhonoproj/1497

Roszkowska, E.; Wachowicz, T. 2013. Metoda TOPSIS i jej rozszerzenia – studium metodologiczne, w T. Trzaskalik (Red.). *Analiza Wielokryterialna: Wybrane Zagadnienia*, 11–40. (in Polish).

Rudnik, K.; Kacprzak, D. 2017. Fuzzy TOPSIS method with ordered fuzzy numbers for flow control in a manufacturing system, *Applied Soft Computing* 52: 1020–1041. https://doi.org/10.1016/j.asoc.2016.09.027

Rudnik, K.; Kacprzak, D. 2015. Rozmyta metoda TOPSIS wykorzystująca skierowane liczby rozmyte, in *XVIII Konferencja "Innowacje w Zarządzaniu i Inżynierii Produkcji"*, 1–3 marca 2015, Zakopane, Polska, 1: 958–968. (in Polish). Available from Internet: http://www.ptzp.org.pl/files/konferencje/kzz/artyk_pdf_2015/T1/t1_0958.pdf

Saaty, T. L. 2005. *Theory and Applications of the Analytic Network Process: Decision-making with Benefits, Opportunities, Costs, and Risks*. 3rd edition. RWS Publications. 352 p.

Šakalys, R.; Sivilevičius, H.; Miliauskaitė, L.; Šakalys, A. 2019. Investigation and evaluation of main indicators impacting synchromodality using ARTIW and AHP methods, *Transport* 34(3): 300–311. https://doi.org/10.3846/transport.2019.9718

Shafiei Kaleibari, S.; Gharizadeh Beiragh, R.; Alizadeh, R.; Solimanpur, M. 2016. A framework for performance evaluation of energy supply chain by a compatible network data envelopment analysis model, *Scientia Iranica: Transactions E: Industrial Engineering* 23(4): 1904–1917. https://doi.org/10.24200/sci.2016.3936

Si, S.-L.; You, X.-Y.; Liu, H-C.; Zhang, P. 2018. DEMATEL technique: a systematic review of the state-of-the-art literature on methodologies and applications, *Mathematical Problems in Engineering* 2018: 3696457. https://doi.org/10.1155/2018/3696457

Simongáti, G. 2010. Multi-criteria decision-making support tool for freight integrators: selecting the most sustainable alternative, *Transport* 25(1): 89–97. https://doi.org/10.3846/transport.2010.12

Solakivi, T.; Ojala, L. 2017. Determinants of carrier selection: updating the survey methodology into the 21st century, *Transportation Research Procedia* 25: 511–530. https://doi.org/10.1016/j.trpro.2017.05.433

Stević, Ž.; Tanackov, I.; Vasiljević, M.; Novarlić, B.; Stojić, G. 2016. An integrated fuzzy AHP and TOPSIS model for supplier evaluation, *Serbian Journal of Management* 11(1): 15–27. https://doi.org/10.5937/sjm11-10452

Subramanian, N.; Ramanathan, R. 2012. A review of applications of analytic hierarchy process in operations management, *International Journal of Production Economics* 138(2): 215–241. https://doi.org/10.1016/j.ijpe.2012.03.036

Sun, C.-C. 2010. A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods, *Expert Systems with Applications* 37(12): 7745–7754. https://doi.org/10.1016/j.eswa.2010.04.066

Trzaskalik, T. 2014. Wielokryterialne wspomaganie decyzji. Przegląd metod i zastosowań, *Zeszyty Naukowe Politechniki Śląskiej. Organizacja i Zarządzanie* 74: 239–263. (in Polish).

Wao, J. O. 2018. Weighted product method in the value engineering process for construction project, *International Journal of Scientific Research and Management* 6(12): EC-2018-158-161. https://doi.org/10.18535/ijsrm/v6i12.ec03

Yu, D.; Wang, W.; Zhang, W.; Zhang, S. 2018. A bibliometric analysis of research on multiple criteria decision-making, *Current Science* 114(4): 747–758. https://doi.org/10.18520/cs/v114/i04/747-758

Zavadskas, E. K.; Antucheviciene, J.; Vilutiene, T.; Adeli H. 2018. Sustainable decision-making in civil engineering, construction and building technology, *Sustainability* 10(1): 14. https://doi.org/10.3390/su10010014

Zavadskas, E. K.; Antucheviciene, J.; Turskis, Z.; Adeli, H. 2016a. Hybrid multiple criteria decision-making methods: a review of applications in engineering, *Scientia Iranica: Transactions A: Civil Engineering* 23(1): 1–20. https://doi.org/10.24200/sci.2016.2093

Zavadskas, E. K.; Govindan, K.; Antucheviciene, J.; Turskis, Z. 2016b. Hybrid multiple criteria decision-making methods: a review of applications for sustainability issues, *Economic Research – Ekonomska Istraživanja* 29(1): 857–887. https://doi.org/10.1080/1331677X.2016.1237302

Zavadskas, E. K.; Turskis, Z. 2010. A new additive ratio assessment (ARAS) method in multicriteria decision-making, *Technological and Economic Development of Economy* 16(2): 159–172. https://doi.org/10.3846/tede.2010.10

Zavadskas, E. K.; Turskis, Z.; Antucheviciene, J.; Zakarevicius, A. 2012. Optimization of weighted aggregated sum product assessment, *Elektronika ir Elektrotechnika* 122(6): 3–6. https://doi.org/10.5755/j01.eee.122.6.1810

Zheng, J. H. 2015. A fuzzy TOPSIS approach based to evaluate the transportation mode selection: an experience in a suburban university, *Advances in Transportation Studies* 1 (Special Issue): 23–34.

Żak, J.; Fierek, S.; Kruszyński, M. 2014. Evaluation of different transportation solutions with the application of macro simulation tools and multiple criteria group decision-making/aiding methodology, *Procedia – Social and Behavioral Sciences* 111: 340–349. https://doi.org/10.1016/j.sbspro.2014.01.067