DEFINING RISKS ON ROAD SECTIONS DURING THE TRANSPORT OF DANGEROUS GOODS IN THE SERBIAN ARMY USING THE LINEAR MATHEMATICAL PROGRAMMING MODEL

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DOI: 10.5937/vojtehg70-36071; https://doi.org/10.5937/vojtehg70-36071

FIELD: Mathematics, Transport, Logistics
ARTICLE TYPE: Original scietific paper

Summary:

Introduction/purpose: The paper presents a model for the selection of a route for the transport of dangerous goods using DEA (Data Envelopment Analysis) models and fuzzy logic systems. The presented model is used to define the risk on road sections during the transport of dangerous goods as well as to select the optimal route for the realization of the transport task.

Methods: The model consists of two phases. The first phase includes the application of DEA models in which formed input and output models are connected in the output DEA final form which shows routes with a satisfactory level of traffic safety and at the same time eliminates routes with low traffic safety. The second phase involves the application of fuzzy logic systems, and as a way out of the fuzzy system, preference is given to one route. Route evaluation is based on six criteria, namely: route length, number of access points, AADT (annual average daily traffic), the number of traffic accidents with fatalities, the number of traffic accidents with the injured and the number of traffic accidents with material damage. When the values of the input criteria are entered, a calculation and evaluation is performed, and, as an exit from the fuzzy system, preference is given to one of the entered routes (the route with the lowest level of risk). The criteria used were defined on the basis of expert assessments.

Results: A user program that represents decision support in traffic service.

Conclusion: The user platform was created for the Matlab R2015a software package with the ability to be adapted to specific problems.

Keywords: DEA model, fuzzy logic system, dangerous goods, risk, route preference.

Introduction

One of the daily activities in the Ministry of Defense and the Serbian Army is the transport of dangerous goods, which is one of constant tasks of traffic service. In the process of managing the transport of dangerous goods, the emphasis is placed on reducing the negative consequences of transport, especially those that affect the safety of population, but also those that cause harmful effects on the environment. One of the crucial factors influencing the safe management of the transport of dangerous goods is the choice of a route on which motor vehicles will move during the transport of dangerous goods.The goal of managing the risks that may occur during the transport of dangerous goods is to minimize the negative consequences for the environment and avoid incidents. With technological development, there is a mass application of modern software systems based on artificial intelligence, while solving the problem of transporting dangerous goods.

This paper presents a model for selecting a route for the transport of dangerous goods using DEA (Data Envelopment Analysis) models and fuzzy logic systems as a type of artificial intelligence systems. The system presented in the paper is a system to help the decision-making bodies of the transport service in choosing one of several possible routes in a particular situation when transporting dangerous goods based on potential risks.

Creating a model involves two phases. In the first phase, the DEA model was applied, and in the second, the fuzzy logic system. The route is evaluated on the basis of six criteria, namely: route length, number of access points, AADT (annual average daily traffic), number of traffic accidents with fatalities, number of traffic accidents with the injured and number of traffic accidents with material damage.

A user platform was created for the practical application of the created model. After the values of the input parameters are entered, calculation and evaluation are performed, and, as an exit from the system, a preference is given to one of the entered routes, according to the minimum risk.

The creation of this and similar models helps in the development of modern systems for solving complex problems in many industries, affecting the ongoing increase of interest in scientific fields that deal with optimizing the process of technical and organizational systems. Wide possibilities in the application of optimization and prediction models enable their constant development and improvement.

The model created in this research facilitates the work of traffic service authorities and reduces the risk of incidental situations by choosing the route that is the safest in relation to the available alternatives. Reducing the possibility of undesirable situations during the transport of dangerous goods increases the level of safety of traffic participants and environmental protection. Since the created model is adaptive in nature, by pre-tuning, it is possible to apply it to solve other problems.

Review of risk assessment models and the definition of the basic concepts for risk modeling

Literature review

Transport and routing of dangerous goods is an area of interest for many authors. Improving the efficiency of the transport process affects the improvement of the efficiency of the system in which it is located. By applying modern software and information systems, it is possible to find the optimal solution not only for the transport of dangerous goods, but also for other problems in various processes.

The subject of interest of many scientific papers is the optimization of the transport process that makes up the subsystem of both military and civilian structures of the logistics system. By using optimization models, it is possible to improve the functioning of many technical and organizational systems. Models that have found application in the optimization of the transport process are also applied in other logistics structures, which shows numerous possibilities of their use. Based on the opinion of Cavaignac et al (2021), by applying the DEA (data envelopment analysis) method, it is possible to improve the business performance of the logistics system. Their study deals with the analysis of the performance of French markets as logistics systems. Comparing the business of several different companies and processing the results using the DEA method give the results of business success of companies, indicating positive and negative influencing factors and potential corrective measures in order to improve the process.

The DEA model has also found application in storage systems, which Karande et al (2019), present in their work. Warehouse management is an extremely challenging task due to a number of activities realized within the warehousing process including internal and external transport processes. Through a study presented by Karande et al, a data envelopment analysis (DEA) model was developed to calculate relative efficiencies. The model was used to rank warehouses and identify the warehouse with the most successful business.

The development of the transport sector promotes rapid economic growth in many countries, but also has a negative impact on the society and the environment, such as pollution and irrational energy consumption. In their study, Tian et al (2020), propose an improved model of DEA based on super-efficiency (SBM-DEA) with weighting to assess the efficiency of regional transport sustainability. An empirical application for measuring the sustainability of transport in Shanxi Province in China, in the period 2000-2015, is presented to demonstrate the effectiveness of the proposed model. Compared to the result obtained by the SBM-DEA model without weighting, the number of effective decision-making units was reduced by the proposed DEA model. The calculated results show that the evaluation result is generally in line with reality, which reflects the relevance of the model.

The research conducted by Vesković et al (2020) presents the definition and evaluation of the criteria that affect the efficiency of railway companies, increase their competitiveness and propose an approach based on the DEA method. The assessment of the efficiency of railway undertakings was considered using the DEA approach. The results show that the proposed approach successfully enables the consolidation of a set of criteria (resource, operational, financial, quality and safety) into a single assessment of the efficiency of railway companies, providing information on corrective actions that can improve the efficiency of railway companies.

In the paper Mitrović Simić et al (2020), the DEA model was applied to define the route with the highest level of traffic safety, in combination with other models such as fuzzy logic systems. Through this paper, the possibilities of combining DEA models with other models are presented, and a model was created representing support in the decision - making of transport service authorities regarding the choice of the safest route. As already shown, the DEA model has an extremely wide application, and the combination with other models further expands the possibilities of its use.

Multi-criteria models are often used in the field of traffic to define the level of road safety in order to protect road users. The process of making decisions about dangerous sections of the road using the model of multi-criteria decision-making involves defining quantitative and qualitative criteria of traffic safety, which Nenadić, D. (2019) explains in his paper. The model used in this paper consists of five quantitative and two qualitative traffic safety criteria. Based on these criteria, the ranking of alternative sections was performed.The analysis of the total number of traffic accidents, by their categories, the analysis of the current state of traffic infrastructure and the annual average daily traffic (AADT) defined seven traffic safety criteria that were assessed and ranked in the first phase of the model by their importance. Using the full consistency method (FUCOM), Pamučar et al (2018), determined the weighted coefficients of the defined criteria and ranked dangerous sections of the road using the weighted aggregate product assessment method (WASPAS) (Baykasoglu & Golcuk, 2020). The obtained results show which section of the road is the safest.

Logistics process management has a significant role in ensuring the competitive growth of the industry. Pamučar et al (2021) in their study propose a new multicriteria decision-making framework (MCDM) to assess the operational efficiency of logistics service providers (LSPs). They present a case study of a comparative analysis of six leading LSPs in India using the proposed framework. Three operational metrics such as annual overheads, annual fuel consumption and delay cost were considered.The result shows that the final ranking is a combined effect of all criteria. It was determined that the method is more stable, gives consistent results, and does not suffer from the problem of changing rank.

In addition to the activities undertaken in order to optimize the process in logistics systems, it is necessary to take measures that relate specifically to the security aspect, which is also one of the elements for improving logistics processes. Risks that appear in the field of logistics, especially in the field of transport, are an area of interest for many authors. Milovanović (2012) in his dissertation pays special attention to the risks that occur during the transport of dangerous goods, which is one of the subjects of this research. In order to safely implement the transport process of dangerous goods, it is necessary to manage the risk, which is a very complex process, and one of the steps in this process is the choice of routes for vehicles transporting dangerous goods.Selecting routes for the movement of vehicles transporting dangerous goods without quantifying the level of risk within each route would lead to the possibility of wrong choice and, consequently, to potential serious consequences that can be caused by dangerous goods transported. In order to make an adequate choice of routes from the aspect of risk management, this paper presents the process of risk management in the transport of dangerous goods, i.e. the phases of which the risk management process consists and a detailed description of each phase separately. The place and importance of the choice of routes for the movement of vehicles transporting dangerous goods was determined, which is one of the initial activities within the analysis of the danger of an incident situation, i.e. the first phase of the mentioned process.Special attention is paid to determining the level of social and individual risk due to the great importance of these types of risks in the choice of routes for the movement of vehicles transporting dangerous goods from the aspect of risk management. By applying optimization methods, it is possible to influence risk management processes, which is also presented in this paper.

Transport of hazardous materials by road poses a risk to the entire environment along the route (traffic participants and the surrounding population). Cassini (1998), in his paper presents the activities most often undertaken in the process of road risk management. In order to minimize the risks, the question arises as to which route the vehicle should use in order to protect the environment (people and the environment). Is it safer to transport through an urban area or less populated areas? Choosing a route is not always an easy task. Various problems are possible with vehicles passing through tunnels and similar areas, which could cause catastrophic consequences in the event of an accident, while the passage of vehicles on the open road in the event of undesirable situations would leave fewer negative consequences. In order to adequately choose the route for the movement of a vehicle carrying dangerous goods, it is necessary to perform risk assessments using an approach that deals with the scenarios of accidents that are likely to occur, their probability and possible consequences. One of the useful steps is the identification of a class of dangerous goods that has a great influence on the choice of route, as stated by Cassini (1998).

Bubbico et al (2004) propose an approach to the transport risk analysis for road and rail transport of hazardous materials based on the use of geographic information systems (GIS) for territorial information management, together with a database of products in the tool for risk assessment. Such an approach makes it possible to accurately take into account local data affecting risk analysis, such as population, accident rate and weather conditions along the entire route, using a system that can be easily updated.

Fabiano et al (2002), in their paper present the conflict of risks that arise when transporting dangerous goods and strategies for choosing the route to move, developing an original location-oriented framework and general applicability at the local level. The realistic assessment must take into account on the one hand the inherent factors (e.g. tunnels, railway bridges, radii of curvature, slope, neighborhood characteristics, etc.) and on the other hand the factors that correlate with traffic conditions. The field data used in this study were collected on the selected highway, by systematic research, providing input data for the database at a given location. The developed technique was applied to the pilot area, taking into account individual and social risk and referring to flammable and explosive scenarios. In this way, risk assessment, sensitive to route characteristics and population exposure, is proposed in order to reduce overall uncertainties in risk analysis.

Based on the review of the literature that considers different methods for optimizing logistics processes and the choice of route for the transport of dangerous goods, it can be seen that the authors used different criteria. The analysis of the criteria used by many authors in their research defined the criteria used to create the model presented in this study.

The concept of risk

A large number of authors define risk as a combination of the probability of occurrence of incident situations and the magnitude of potential consequences of the incident situation (Lavell, 2000; Fabiano et al, 2002; Cassini, 1998). This definition of risk is the starting definition of the concept of risk. There are many different factors in different spheres that can cause an incident situation. One of the biggest difficulties in defining the level of risk is defining the parameters that determine the probability of occurrence of incident situations and the magnitude of potential consequences. Risk can also be defined as the probability of harmful outcomes resulting from the interaction between two hazards[1], vulnerabilities of the community and the natural environment. In 1994, the National Assembly of the Republic of Serbia defined risk as the expected number of lost persons, damage to private property and disruption of economic activities due to hazards. Based on the definitions of risk, it is concluded that there are three elements that define risk, and they are:

1) type of hazard (Lavell, 2000),
2) vulnerability, and
3) the risk element.

When defining risk, one can talk about individual and social risk. First of all, it is necessary to terminologically define these two terms, describe the differences between them and define their limit values. Individual risk represents the annual mortality rate of the average individual who is constantly exposed to danger without protective equipment within the zone of influence (Milovanović, 2012). Social risk is the cumulative value of the probability of an accident with several victims within the impact zone

[1] Hazard-potential harmful physical events that can occur in the context of vulnerability of population, infrastructure and production, and that lead to economic and social losses and can reach disaster levels.

(Ormsby & Le, 1988; Castillo, 2004). The frequency of accidents depends on:

1) types and quantities of hazards,
2) processes that cause accidents, and
3) levels of applied security measures.

The magnitude of the consequences depends on:

1) population structure,
2) effects caused by the danger during the occurrence of the incident situation, and
3) the ability of participants to avoid the consequences of the accident and apply available measures to control the consequences.

In order to effectively manage the risk of an incident during the transport of dangerous goods, it is necessary to carry out activities that are interdependent and to have relevant data on the characteristics of dangerous goods, the number of incidents from the previous period by dangerous goods classes, population and environmental consequences, incident situations in the previous period and the capacities of the response services in case of an incident situation (ambulance, firefighters and police). As already mentioned, risk is the product of the probability of an accident involving a vehicle transporting dangerous goods and the number of inhabitants who are potentially exposed to dangerous goods due to the accident (Milovanović, 2012):

$$\text{Risk} = \text{probability} * \text{consequences} \qquad (1)$$

Probability is the rate of accidents involving vehicles transporting dangerous goods in units of the number of accidents per vehicle per kilometer, and the consequences of the degree of population potentially exposed to accidents involving vehicles transporting dangerous goods along the road intended for transport of dangerous goods. In order to determine the probability of an accident with the participation of vehicles transporting dangerous goods, it is necessary to collect all data on traffic accidents and traffic flows for all road sections that are analyzed. The consequences of traffic accidents with dangerous goods are expressed through the population that is in the zone of influence of dangerous goods.Transport of dangerous cargo represents the type of transport for which the greatest risks and potential magnitude of damage to the population and the environment are associated, so that in accordance with that it is necessary to influence the reduction of risk, i.e. manage risk when transporting dangerous goods. By starting to deal with the risk of occurrence of incidental urbanization in transport of dangerous goods, the probability of occurrence of an incident situation and the magnitude of the consequences for the environment are reduced. There are two types of activities aimed at reducing primary risk, namely (Milovanović, 2012):

1) reduction of the subsequent risk, and
2) control of the expected risk.

In addition to standard physical and chemical properties, dangerous goods also have dangerous properties, which is why they are classified in the category of dangerous goods. These characteristics are reflected in the types and degree of danger of dangerous goods and have a considerable influence on the choice of the section for the movement of vehicles transporting this type of cargo. In addition to the characteristics of dangerous cargo, the important factors are the amount of cargo transported by a given road section, current meteorological conditions, the characteristics of the terrain on which the road section is located, etc. In order to effectively manage the risks on road sections during the transport of dangerous goods, it is necessary to analyze the dangers of incidents. A hazard analysis is realized through three phases (Milovanović, 2012):

1) hazard identification,
2) consequence analysis, and
3) risk assessment.

The choice of the route for the movement of vehicles transporting dangerous goods based on the size of the risk is an important factor in the risk management process for the transport of dangerous goods. The size of the risk is one of the crucial factors for choosing the route when transporting dangerous goods. Consequently, new methods are being developed on a daily basis to select optimal routes for the transport of dangerous goods, with the aim of managing road risks. Based on the analysis of influential factors on potential routes for the transport of dangerous goods, the route for the transport of dangerous goods is selected. This is the first phase in the process of risk management during the transport of dangerous goods and is a key factor for effective risk management from incidents (Milovanović, 2012).

The concept of linear programming

The mathematical methodology for modeling and solving the problem of finding the maximum or minimum of a linear function, under conditions expressed as linear equations or inequalities, is called linear programming. The term "programming" is used as a synonym for planning, i.e. determining the optimal solution. This means determining the values of variables such that they give the optimal value of the objective function, while satisfying the conditions (constraints).

Linear programming is a special case of mathematical programming where the function of the goal and the constraints are linear. Such mathematical models can present the problems of resource allocation, vehicle movement planning, various problems of production in industry, problems in the economy, etc. The problem of linear programming was formulated by the Soviet mathematician Leonid Kantorovich in 1939 (Kantorovich, 1960). The first models were used in wood production, and during the Second World War Kantorović worked for the army to optimize military operations. The method of solving the problem was not publicly known until 1947 when George B.Danzig published the simplex algorithm (Dantzig, 1947).

An overview of current models for road risk assessment

The choice of a route for the transport of dangerous goods is one of the key activities during the planning and organization of transport. Given that the route used by vehicles during the transport of dangerous goods is an extremely important part of the transport process, a number of different methodologies have been developed for selecting routes for vehicles transporting dangerous goods: from case studies involving risk analysis, the route is performed on the basis of data obtained from statistical analyzes and research on the number of incident situations, until the choice of routes is resolved through vehicle routing algorithms (Thomson, 1999).

Based on the above, it is concluded that there are numerous methodologies developed with the aim of selecting routes for the movement of vehicles transporting dangerous goods from the aspect of risk management. The most important methodologies necessary for understanding the improved methodology related to the selection of routes for vehicles transporting dangerous goods based on the levels of individual and social risk as well as on the levels of absolute and specific risk are presented in the following section (Milovanović, 2012).

a) methodology for the selection of routes for the movement of vehicles transporting dangerous goods based on the size of individual and social risk and minimum costs

The problem that defines this methodology is better known as the "minimum cost problem of goods flows", and was developed by three Italian authors: Pierre Leonelli, Sara Bonvincini and Giulia Spadoni. In order to define and select the optimal route for the movement of vehicles transporting dangerous goods, it is necessary to define the values of the level of individual and social risk. To determine these two types of risk, there are two software programs defined by the same authors: TransIn (for determining the level of individual risk) and TransSoc (for determining the level of social risk). For the optimization of routes within this methodology, the software package OPTHIPATH selects the optimal route based on the minimum total costs and the minimum size of individual and social risk between the source and the destination point (Milovanović, 2012).

b) methodology for the selection of routes for road and rail transport using social risk curves

This methodology presents a simplified risk analysis for the transport of dangerous goods by road and rail. It is based on the use of data from a large database, taking into account the size of impact zones for several predefined incident scenarios, and on the choice of several average values of selected parameters relevant to the type of transport activity (i.e. for the type of transport and the type of dangerous goods) and the category of road (roads), (Bubbico et al, 2004).

c) methodology for determining the level of risk and decision-making strategies in the transport of dangerous goods

This methodology is based on determining the individual and social level of risk in order to choose routes for the transport of dangerous goods. It was developed by four Italian authors. Decisions made within the defined methodology are made based on the level of individual and social risk (Fabiano et al, 2002).

d) methodology for the selection of routes for the movement of vehicles transporting dangerous goods on the basis of specific and absolute risk

This methodology, based on the selection of routes for the movement of vehicles transporting dangerous goods on the basis of specific risk and developed by the American Road Institute, consists of eight steps. All steps within the defined methodology are interdependent, so that it is only possible to choose the route for the transport of dangerous goods by implementing all eight steps (Milovanović, 2012).

One of the most important aspects of the methodology for optimizing the routes for vehicles transporting dangerous goods is a high level of flexibility sufficient to make certain changes within the methodology and / or supplement it with certain goals defined by various stakeholders.The methodology for selecting routes for vehicles based on absolute risk is defined by the Institute for Geological Research in the Netherlands and is based on defining the optimal route for vehicles transporting dangerous goods for each phase separately, based on the objectives and scenarios defined within that phase and the previously completed phases. For each of the phases, special mathematical models were defined individually, on the basis of which optimizations were performed. The limitations defined within the methodology apply and they apply to all phases (Castillo, 2004).

Proposal of a model for risk assessment on road sections during the transport of dangerous goods in the Serbian Army

The whole process includes a series of activities that need to be implemented and consists of two phases. The first phase involves the application of the DEA model which defines routes that have a minimum level of risk. At the same time, DEA models eliminate routes that have an extremely high level of risk. In this step, two DEA models are formed to determine the state of traffic safety on the observed routes: an input-oriented model and an output-oriented model. Both models are connected in the output DEA-final form in order to, on the one hand, obtain routes that enter the further processing process and, on the other hand, to eliminate routes that do not meet the set conditions sufficiently (routes that do not have the required level of security traffic). In the second phase, after identifying the routes with a minimum degree of risk, route evaluation is performed using the fuzzy logic system (FLS). The FLS was created through several steps shown in Figure 1. The presented FLS gives the final ranking of the routes for the transport of dangerous goods, i.e. it defines the optimal route for the transport of dangerous goods. A user platform has been created for the created model, through which the practical application of the model is realized.

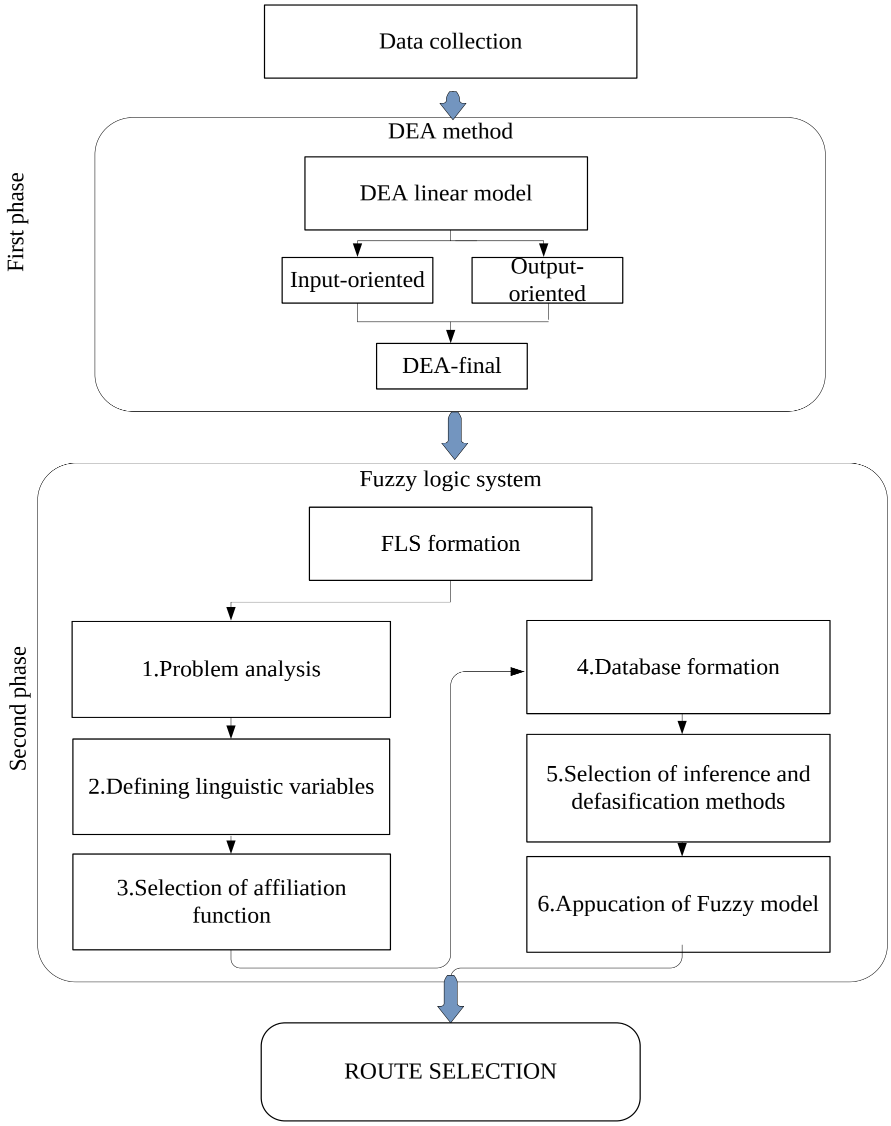

Figure 1– Research realization process
Рис. 1 – Процесс проведения исследования
Слика 1 – Процес реализације истраживања

Phase I - DEA model

The DEA method is one of the most widely used tools for measuring efficiency. It was used to compare organizations, companies, regions and countries. It has made significant contribution to logistics (Cavaignac et al, 2021), warehousing systems (Karande et al, 2019) and transport (Tian et al, 2020), as well as to logistics and supply chain subsystems (Amirteimoori & Khoshandam, 2011), which could be seen in the literature review at the end of the paper.

In addition to the assessment of efficiency, this method was used in defining the degree of safety and risk in transport and traffic systems (Ranković et al, 2011), which was applied in this paper. The specific problem that is the core of this research is the choice of the optimal route for the transport of dangerous goods from the aspect of traffic safety, using the model of linear mathematical programming. The research considered six alternative routes for which data related to eight parameters were collected. The database of the Traffic Safety Agency was used for the realization of the research.

The DEA-Data Envelope Analysis is a numerical approach based on the evaluation of the performance of a set of similar entities (organizational or production units), i.e .units to be decided (DMU - Decision Making Unit) (Cooper, 2014).The DEA is based on an extension of Farrell's 1957 efficiency measure (Farrell, 1957), upgraded with the method of linear programming by Charnes, Cooper, and Rhodes in 1978, resulting in a new method for calculating efficiency called the Data Envelope Analysis (DEA).

Creating virtual inputs (outputs) involves determining the weight coefficients associated with the inputs and outputs that participate in the analysis, in accordance with the objectives of the DMU. After calculating the efficiency measure for each DMU, the DEA analysis provides information on whether the DMU, based on its inputs and outputs, is relatively efficient or not, compared to other DMUs included in the analysis. The algorithm is basically reflected in the iterative solution of a linear program for each point in the data set. It is the standard basic algorithm of the DEA methodology and is widely used in numerical terms. This algorithm must solve as many linear programs as there are points in the data set (Dawson et al, 2000). In the process of applying the DEA model, two models were formed to determine the state of traffic safety during the transport of dangerous goods on the observed routes: input-oriented and output-oriented models. After that, based on the obtained results, the alternatives whose values deviate from 1 are eliminated from further calculations. In the process of traffic safety management, it is necessary to know the existing situation, which may include dangerous parts of the road (Nenadić, 2019).

There are two basic types of DEA models: the CCR model and the BCC model. In this case, the CCR (Charns, Cooper and Rhodes modeling model) model was used (Vesković et al, 2020). The CCR model is also known as the DEA model with constant volume yield, and the BCC model is known as the DEA model with variable volume yield. CCR models measure the overall technical efficiency of a unit, which includes pure technical efficiency and volume efficiency. It is assumed that the units operate with a constant return on volume, i.e. that the increase in the input must result in a proportional increase in the output (Jeremić, 2012).

Mathematically, the DEA method can be described by models that consist of a goal function and two types of constraints. In this case, two DEA CCR models were formed according to the input-oriented model (max) and according to the output-oriented model (min) (Srdjevic et al, 2002).

The input-oriented CCR model is obtained by converting a nonlinear task into a linear one which is solved by the method of linear programming. This gives an optimal solution, where the optimization criterion is the maximization of the value of the objective function under given constraints (system of linear inequalities) (Mitrović Simić et al, 2020). The DEA CCR input-oriented model (max) is:

$$DEA_{input} = \max \sum_{i=1}^{m} W_i \, X_{i-input} \tag{2}$$

St:

$$\sum_{i=1}^{m} W_i \, X_{ij} - \sum_{i=m+1}^{m+s} W_i Y_{ij} \leq 0, \quad j=1,\ldots\ldots\ldots\ldots, n \tag{3}$$

$$\sum_{i=m+1}^{m+s} W_i \, Y_{i-output} = 1 \tag{4}$$

$$Wi \geq 0, \quad i=1,\ldots\ldots\ldots\ldots, m+s \tag{5}$$

The DEA consists of m input parameters for each alternative Xij, while S shows the output parameters for each alternative Yij, taking into account the weights of the parameters denoted by wi, n represents the total number of DMUs. The DEA CCR output-oriented model (min) is:

$$DEA_{output} = \min \sum_{i=m+1}^{m+s} W_i \, Y_{i-output} \tag{6}$$

St:

$$-\left(\sum_{i=1}^{m} W_i \, X_{ij} \right) + \sum_{i=m+1}^{m+s} W_i Y_{ij} \geq 0, \quad j=1,\ldots\ldots\ldots\ldots, n \tag{7}$$

$$\sum_{i=1}^{m} W_i X_{i-input} = 1 \tag{8}$$

$$W_i \geq 0, \quad i=1,\ldots\ldots, m+s \tag{9}$$

Finally, to obtain the efficiency index for each DMU, the equation is applied:

$$DEA_{safety} = \frac{\min output}{\max input} \tag{10}$$

Phase II - Fuzzy logic system

Artificial intelligence is one of the computer fields. The main goal of artificial intelligence is to enable computers to behave like humans. This effect is achieved by using a fuzzy system. The fuzzy theory is designed to represent human knowledge and reason in such a way that it can be easily presented on a computer. The creator of fuzzy logic is Lotfi Zadeh (Zadeh, 1965). The fuzzy system has the property of "quantification of uncertainty". Unlike formal logic, in which reasoning is performed with two values(true-false, 0-1), fuzzy logic uses numbers from the interval (0.1).This interval is much closer to reality, human thinking and expression. During the modeling of the fuzzy logic system, it is necessary to go through all six steps listed in Figure 1 and finally apply the created model. An explanation of these steps is provided below.

1) Problem analysis

In order to determine the number of variables and their interdependence, a detailed analysis of the problem is performed when modeling a fuzzy logic system. If the problem is complex, the system can be divided into several smaller subsystems, the goal and purpose of each subsystem is determined, after which the way of connecting these subsystems and priorities among them is determined.

2) Defining linguistic values

As already mentioned, linguistic variables take values from a spoken language or are artificially synthesized and represented by fuzzy sets. In this case, it was assumed that the designed fuzzy system, for the selection of the route for transport of dangerous goods, contains six input linguistic variables (two input variables (out of eight) used in creating the previously presented DEA model were not taken into account) and system load (a large number of rules) to facilitate the modeling of fuzzy systems and perform simpler manipulation of parameters, as follows:

- ❖ Route length,
- ❖ Number of access points,
- ❖ AADT (annual average daily traffic),

- Number of traffic accidents (TA) with fatalities,
- Number of traffic accidents with the injured, and
- Number of traffic accidents with material damage,

as well as the output linguistic variable Route preference.

For all inputs and outputs, it is necessary to determine the number and type of membership functions. A larger number of membership functions increase the total number of rules, which makes it difficult to set up the system, so it is recommended, in accordance with the nature of the variable, to start with the smallest number of membership functions. Reducing the number of membership functions must not be done to the detriment of the quality of the description of the variable. Starting from the above settings, it is defined that in the model each input variable has three linguistic values, and the output variable has six. The linguistic values assigned to all input variables were: Route length (Small, Medium, Large), Number of access points, AADT, Number of TA with fatalities, Number of TA with the injured and Number of TA with material damage (Small, Medium, Large). The output variable preference by route has the values: Very small, Small, Medium small, Medium, Large and Very large preference.

A large number of linguistic values were not needed because this is a decision support system, so it does not require enormous precision. With three linguistic values, a satisfactory gradual change in output values was achieved, which limits the number of rules to 729, a domain that an expert can control. By the way, most fuzzy systems contain 3, 5 or 7 variables, and practice has shown that people manipulate well with a maximum of 7 values.

3) Selection of affiliation functions

The choice of affiliation functions and their range in the confidence interval is one of the most important phases.The fuzzy system used Gaussian curves for input and output variables. In this way, a satisfactory sensitivity of the system is achieved. Figures 2 and 3 show the membership functions of the input variables and the output variable.

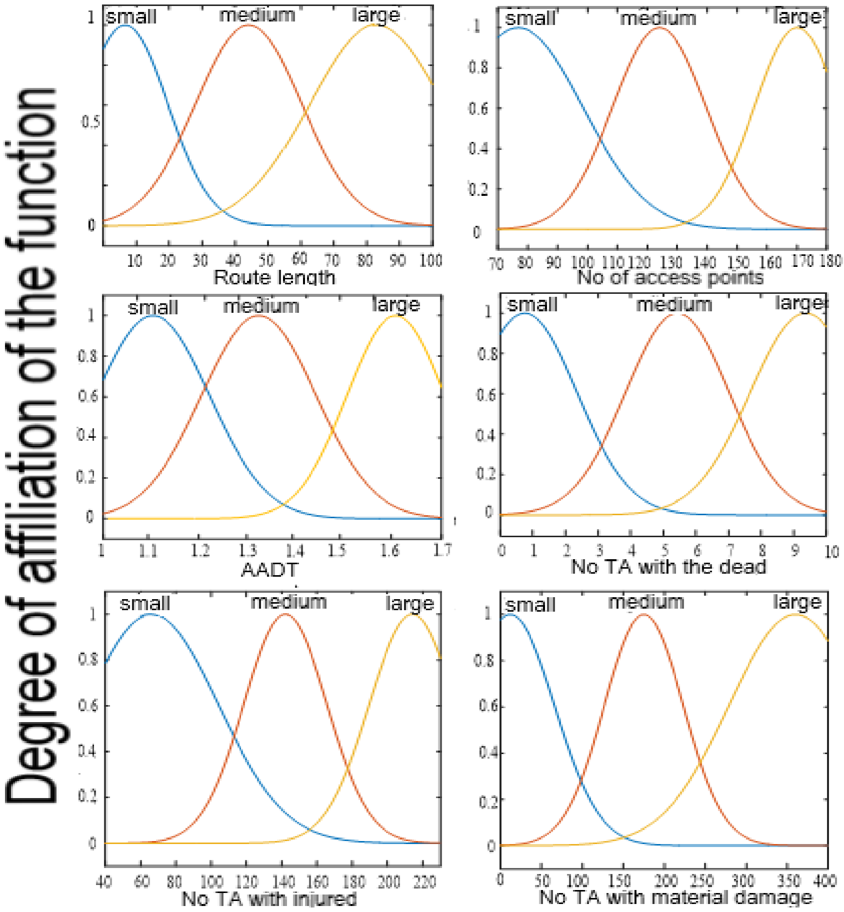

Figure 2 – Function of belonging of linguistic variables: Length of the route, Number of access points, AADT, Number of TA with fatalities, Number of TA with the injured and Number of TA with material damage

Рис. 2 – Функция принадлежности лингвистических переменных: Длина маршрута, количество точек доступа, СДТ, количество ДТП со смертельным исходом, количество ДТП с пострадавшими и количество ДТП с материальным ущербом

Слика 2 – Функција припадности лингвистичких промењивих: дужина руте, број приступних тачака, ПГДС, број СБН са погинулим лицима, број СБН са повређеним лицима и број СБН са материјалном штетом

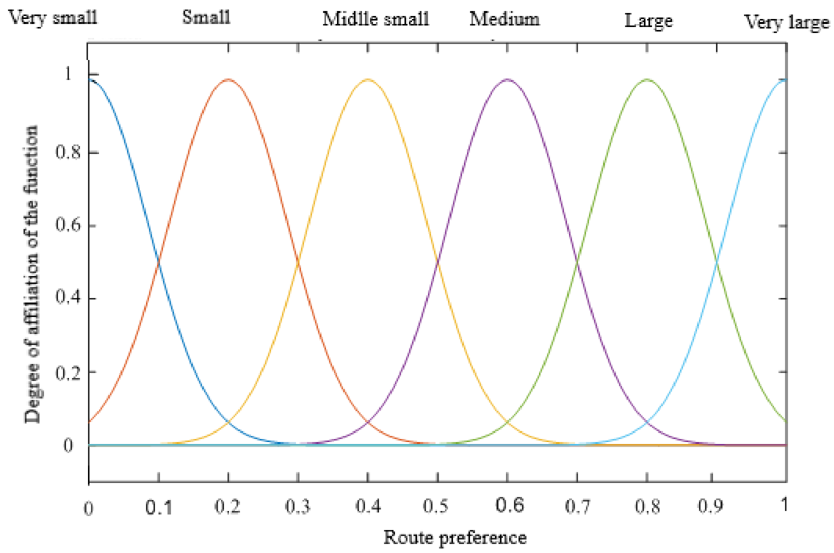

Figure 3 – Output variable membership functions
Рис. 3 – Функции принадлежности выходных переменных
Слика 3 – Функције припадности излазне промењиве

4) Forming a database of rules

Linguistic rules are the connection between the inputs and outputs of a fuzzy system. Expert knowledge of the process can be expressed through a number of linguistic rules consisting of spoken or artificial language words. When it comes to complex systems, one of the big problems is the lack of standard and systematic methods for transforming engineering knowledge or experience into fuzzy rules. There is also no general procedure for selecting the optimal number of rules, as many factors influence such a decision, which is very important for the speed of the system (Božanić & Pamučar, 2014).

The domain expert enters his knowledge primarily through production rules. At the beginning, it is important that for each combination of the input values of the linguistic variables, the expert suggests appropriate output values. In this case, there are six input linguistic variables (n = 6), with three linguistic values each (M = 3) and they can be combined in the database with a total of $M^n = 3^6 = 729$ rules. The weighting coefficients of the criteria were determined using the LMAW method. The method of aggregation of the weight of the premise of the rule is presented in (Pamučar et al, 2021).

5) Choice of the inference and defasification method

The methods most commonly used in direct inference are MIN-MAX and PROD-SUM (Mamdani method). In the initial phase of the system development, the MIN-MAX method was used. This method is a common choice when it is not important to manage the entire confidence interval of the output variable. However, a large number of system simulations have shown that the MIN-MAX method is inappropriate. One of the basic requirements was to achieve a satisfactory level of system sensitivity, which means that with certain small changes in the input, the output from the fuzzy system must also have small changes, which could not be achieved using the MIN-MAX method.The Matlab R2015b software package was used to construct the fuzzy logic system. In order to increase the sensitivity of the system, the PROD-SUM method of direct inference was used, as the best one offered by the Matlab software package.

Application of the model

To test the model, a transport task was used to transport dangerous goods from the Vasa Čarapić barracks (Banjica) to the Rastko Nemanjić barracks (Pančevo). Six routes were defined and taken into account for the realization of transport. Taking into account the fact that it is an urban zone where the vehicle moves, the safety of transport is the primary task during planning, primarily due to the increased concentration of pedestrians who represent the most endangered category of traffic participants, and then environmental protection.

Phase I - application of the DEA model

Based on expert consultations, eight input and output parameters in total have been defined, the validity of which has been confirmed in research work (Mitrović Simić et al, 2020). A list of four criteria was formed for the inputs: the route length expressed in kilometers, the number of access points, the AADT and the road slope. The following were taken as the outputs: the number of traffic accidents with fatalities, the number of traffic accidents with severely injured persons, the number of traffic accidents with lightly injured persons and the number of traffic accidents with material damage. The approximate numerical values are taken for the used criteria, presented in Tables 1 and 2.

Table 1 – Route parameters in relation to the formed list of inputs
Таблица 1 – Параметры маршрута по отношению к сформированному списку входных данных
Табела 1 – Параметри рута у односу на формирану листу импута

ROUTE	Route lenght (KM)	Number of access points	AADT (veh/day)	Road slope(%)
1.	73.37	92	16340	0.281
2.	33.28	88	14592	0.232
3.	52.27	123	15466	0.199
4.	34.6	140	10019	0.321
5.	32.23	132	11521	0.359
6.	53.36	161	10103	0.253

Table 2 shows the values of the observed routes in relation to the output parameters.

Table 2 – Route parameters in relation to the formed output list
Таблица 2 – Параметры маршрута относительно сформированного списка выходных данных
Табела 2 – Параметри рута у односу на формирану листу аутпута

Route	No.TA with fatalities	No. TA with seriously injured persons	No. TA with slightly injured persons	No. TA with material damage
1.	5	73	77	168
2.	3	101	104	255
3.	4	93	98	247
4.	4	202	105	254
5.	2	121	123	367
6.	4	51	54	73

In the following section, two DEA models are presented: input and output oriented models, in order to show the routes that had a satisfactory level of safety and which were taken into further ranking. The formed linear programming algorithms were solved using Lingo 18. The given examples of the input-oriented model were solved using equation (2), and the output-oriented one was solved using equation (6), for route 1 whose parameters are shown in Tables 1 and 2. All inputs belong to the benefit group, because they need to be maximized, and the outputs belong to the cost group and need to be minimized.

$DEA_{INPUT}=MAX$ =73.37*w1+92*w2+16340*w3+0.281*w4;
73.37*w1+92*w2+16340*w3+0.281*w4-
(5*w5+73*w6+77*w7+168*w8)<=0;
33.28*w1+88*w2+14592*w3+0.232*w4-
(3*w5+101*w6+104*w7+255*w8)<=0;
52.27*w1+123*w2+15466*w3+0.199*w4-
(4*w5+93*w6+98*w7+247*w8)<=0;
34.6*w1+140*w2+10019*w3+0.321*w4-
(4*w5+202*w6+105*w7+254*w8)<=0;
32.23*w1+132*w2+11521*w3+0.359*w4-
(2*w5+121*w6+123*w7+367*w8)<=0;
53.36*w1+161*w2+10103*w3+0.253*w4-
(4*w5+51*w6+54*w7+73*w8)<=0;
5*w5+73*w6+77*w7+168*w8=1;
w1>0;w2>0;w3>0;w4>0;w5>0;w6>0;w7>0;w8>0;

The obtained results show that the objective function is equal to 1.000.

$DEA_{outout}=MIN$=5*w5+73*w6+77*w7+168*w8;
-73.37*w1-92*w2-16340*w3-
0.281*w4+(5*w5+73*w6+77*w7+168*w8)>=0;
-33.28*w1-88*w2-14592*w3-
0.232*w4+(3*w5+101*w6+104*w7+255*w8)>=0;
-52.27*w1-123*w2-15466*w3-
0.199*w4+(4*w5+93*w6+98*w7+247*w8)>=0;
-34.5*w1-140*w2-10019*w3-
0.321*w4+(4*w5+202*w6+105*w7+254*w8)>=0;
-32.23*w1-132*w2-11521*w3-
0.359*w4+(2*w5+121*w6+123*w7+367*w8)>=0;
-53.36*w1-161*w2-10103*w3-
0.253*w4+(4*w2+51*w6+54*w7+73*w9)>=0;
73.37*w1+92*w2+16340*w3+0.281*w4=1;
w1>0;w2>0;w3>0;w4>0;w5>0;w6>0;w7>0;w8>0;

The obtained results for output oriented route 1 also show that the objective function is equal to 1.000. The algorithms of other routes were solved in the same way and the final results of the DEA model are shown in Table 3. The DEA-final values were obtained applying equation (10).

Table 3 – Traffic safety situation on the analyzed routes after the application of the DEA model
Таблица 3 – Ситуация с безопасностью движения на анализируемых маршрутах после применения модели DEA
Табела 3 – Стање безбедности саобраћаја на анализираним рутама након примене модела ДЕА

ROUTE	DEA-INPUT	DEA-OUTPUT	DEA-FINAL
1.	1.000	1.000	1.000
2.	1.000	1.000	1.000
3.	1.000	1.000	1.000
4.	0.852	0.999	1.172
5.	1.000	1.000	1.000
6.	1.000	0.249	0.249

Routes 4 and 6 are eliminated from the further processing process due to poor traffic safety characteristics. On these routes, it is necessary to take certain corrective measures in order to improve traffic safety. Routes with a value of DEA-final=1.000 are taken into further consideration.

Phase II - Application of the fuzzy logic system

The application of the system is an integral step in the life cycle of the system. The model needs to be applied and, if necessary, certain corrective measures, changes and improvements need to be taken, which is relatively easy in a fuzzy system because it is characterized by the property of adaptability. When designing a fuzzy system, the interval of (0.1) was taken as the confidence interval of the output variable route preference. During the practical application of the system, the interval (0.1) can be adjusted depending on the obtained preference according to the route. For transport, six routes - alternatives were considered, and after the application of the DEA model, further consideration is given, i.e. in the second phase of the work, four alternatives were taken. The fuzzy logic system was applied to routes 1, 2, 3 and 5, which were mentioned earlier, because after the application of the DEA model, these alternatives proved to be routes that meet the necessary conditions and were taken into further processing.

Table 4 shows the values of the input variables in the fuzzy logic system for each route (alternative). The database of the Traffic Safety Agency was used for the realization of the research.

Table 4 – Values of the input variables in the fuzzy logic system
Таблица 4 – Значения входных переменных в системе нечеткой логики
Табела 4 – Вредности улазних промењивих у fuzzy логички систем

Route	Route length(KM)	No.of access point	AADT	No. TA with fatalities	No. TA with injured persons	No. TA with material damage
A1	73.37	92	16340	5	75	168
A2	33.28	88	14592	3	102.5	255
A3	52.27	123	15466	4	95.5	247
A4	32.23	132	11521	2	122	367

After entering the input parameters into the fuzzy logic system, the calculation and evaluation of these alternatives is performed. The results of the calculation, i.e. the output values of the fuzzy logic system are shown in Table 5.

Table 5 – Evaluation of the alternatives
Таблица 5 – Оценка альтернатив
Табела 5 – Евалуација алтернатива

Alternatives	Route preference	
	Numerical value	Linguistic description
A1	0.567	Medium small
A2	0.680	Medium
A3	0.519	Small
A4	0.668	Medium

After the evaluation of the alternatives, it was found that there was the greatest preference for alternative A2. The ranking of the alternatives can be displayed as A2> A4> A1> A3.

For the developed fuzzy logic system, a user program was created for the practical realization of the model. The user platform was created in the Matlab R2015b software package. By entering the term "PROGRAM" in the command line of the Matlab software package, a program is launched to select the route for the transport of dangerous goods based on the minimum degree of risk. The user form is shown in Figure 4.

Figure 4 – User form of the program
Рис 4. – Форма пользовательской программы
Слика 4 – Корисничка форма програма

Clicking on the "Run program" button opens a fuzzy logic model in which the user enters the desired values of input variables. The values of the input and output variable criteria are shown in Tables 4 and 5. The values are entered by typing in the window of the specified criteria located on the user form, which is shown in Figure 5.

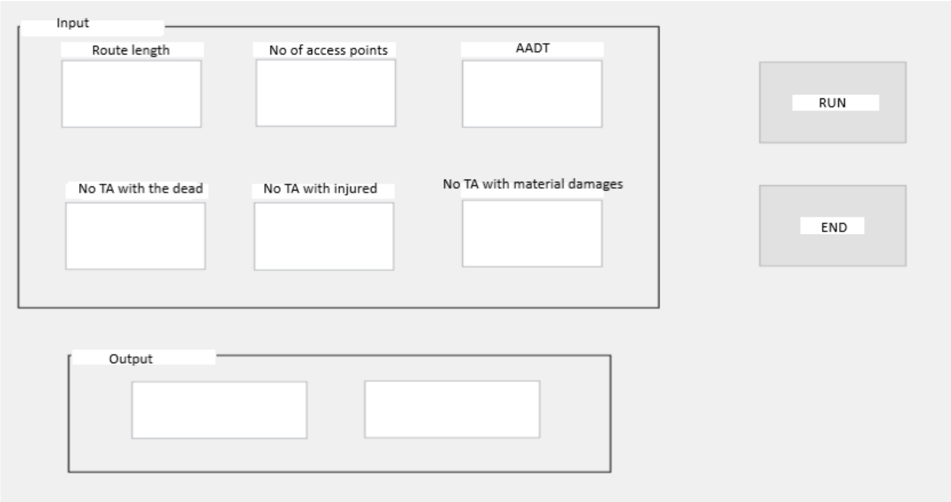

Figure 5 – Window for entering the input values into the system and displaying the output values from the FLS
Рис. 5 – Окно для ввода входных значений в систему и отображения выходных значений из ФЛС
Слика 5 – Прозор за унос улазних вредности у систем и приказ излазних вредности из FLS-а

Activating the "RUN" button starts the developed fuzzy system in which the calculation and evaluation of routes is performed. The presented model expands the theoretical framework of knowledge in the field of choosing the route for the transport of dangerous goods. The existing problem can be considered with a new methodology, which provides a basis for further theoretical and practical upgrades.

Conclusion

The model used to select the route for the transport of dangerous goods using the DEA model and fuzzy logic systems is based on the minimum level of risk. Fuzzy logic systems belong to a group of models that are based on artificial intelligence and can be used to support the decision-making bodies of the transport service in the Ministry of Defense and the Serbian Army. Technological development leads to the development of new models for the selection and optimization of the route by which dangerous goods are transported. The primary goal is to reduce the risks and consequences of incidents.

Based on the data collected from the database of the Traffic Safety Agency, eight criteria for creating DEA models have been defined. For the input values (inputs), the following criteria were taken: the route length, the number of access points, the AADT and the road slope. For the output values(outputs), the following criteria were taken: the number of traffic accidents with fatalities, the number of traffic accidents with seriously injured persons, the number of traffic accidents with slightly injured persons and the number of traffic accidents with material damage. The algorithms for the inputs and the outputs were solved using the Lingo18 software package.The last step in the implementation phase of the DEA model was the definition of DEA final results that eliminate routes with extremely low levels of safety and on which appropriate measures need to be taken in order to improve traffic safety. In this case, two routes were eliminated out of the total of six alternatives, and these routes were not considered in the fuzzy logic system that includes the second phase of work. The following criteria were taken as the input values into the fuzzy logic system: the route length, the number of access points, the AADT, the number of traffic accidents with fatalities, the number of traffic accidents with injured persons and the number of traffic accidents with material damage. In the phase of the application of the fuzzy logic system, the total number of the input criteria was reduced compared to the DEA model for simplifying system modeling and for easier manipulation of the total number of rules, 729, with the six input criteria.

All input variables are represented by three membership functions, and the output variable is defined by six membership functions. One of the basic requirements when modeling the system was the existence of a certain degree of sensitivity of the system, so Gaussian bell functions were used as functions for the input and output variables. All rules in the fuzzy logic system are determined by applying the method of aggregation of weight premise rules (ATPP) (Božanić & Pamučar, 2014), which allows the formation of a database based on experience and intuition. Based on the number of input variables and the number of their membership functions, a basic base of 729 rules was defined. The values of the weight coefficients were determined using the LMAW method (Pamučar et al, 2021). In order to increase the sensitivity of the system, the PROD-SUM method of direct inference was used.

The presented model was tested on the example of choosing a route for the transport of dangerous goods. Four possible routes were considered and evaluated on the basis of the six previously mentioned criteria. After the calculation and evaluation of the individual routes, the values of the output variable of the fuzzy system were obtained in the user form, that is, the preference for the route was obtained in the form of a numerical value and a linguistic descriptor.

Based on the output values of the system for each route, the observed routes were compared and ranked. In this case, route 2 proved to be optimal for the realization of the transport task. The advantage of using this system is the presence of the adaptability feature which gives the possibility to adjust the base of the fuzzy rule. Fuzzy inference rules are essential for the management of dangerous goods transport, due to the descriptive approach and the heuristic solution of the problem. The fuzzy logical model transcends the limitations of conventional evaluation methods. This system is implemented as a user program within the Matlab software package. As such, it is suitable for application in a dynamic environment and real-time decision making. The presented system leaves room for further research that should move in the direction of identifying additional parameters that may affect the choice of a route for the transport of dangerous goods and the implementation of additional decision criteria in the presented model. The presented software can be additionally tested by solving problems from the real environment in the units of the Serbian Army and adjusted to the needs and requirements of users.

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ВЫЯВЛЕНИЕ РИСКОВ НА УЧАСТКАХ ДОРОГ ПРИ ПЕРЕВОЗКЕ ОПАСНЫХ ГРУЗОВ СЕРБСКИХ ВООРУЖЕННЫХ СИЛ С ИСПОЛЬЗОВАНИЕМ МОДЕЛИ ЛИНЕЙНОГО МАТЕМАТИЧЕСКОГО ПРОГРАММИРОВАНИЯ

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РУБРИКА ГРНТИ: 27.47.19 Исследование операций,
73.47.12 Организация управления и автоматизированные системы управления транспортом,
81.88.00 Материально-техническое снабжение. Логистика
ВИДСТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В статье представлена модель по выбору маршрута перевозки опасных грузов с использованием моделей DEA (Data Envelopment Analysis) и систем нечеткой логики. Представленная модель используется для выявления рисков на участках дорог при перевозке опасных грузов, а также для выбора оптимального маршрута для реализации транспортной задачи.

Методы: Модель состоит из двух этапов. Первый этап включает в себя применение моделей DEA, в которых сформированные входные и выходные данные объединяются в конечной форме выходной DEA модели, которая показывает маршруты с удовлетворительным уровнем безопасности дорожного движения и в то же время устраняет маршруты с низкой безопасностью дорожного движения. Второй этап предполагает применение систем нечеткой логики, при выходе из которой рекомендуется один из маршрутов. Оценка маршрута основана на шести критериях, а именно: расстояние маршрута, количество точек доступа, СДТ (среднегодовой дневной трафик), количество дорожно-транспортных происшествий со смертельным исходом, количество дорожно-транспортных происшествий с пострадавшими и количество дорожно-транспортных происшествий с материальным ущербом. При вводе значений входных критериев выполняется вычисление и оценка, а при выходе из нечеткой системы рекомендуется один из введенных маршрутов (маршрут с наименьшим уровнем риска). Используемые критерии были определены на основании проведенной экспертизы.

Результаты: Пользовательская программа используется в качестве поддержки при принятии решений органами управления дорожным движением.

Выводы: Пользовательская платформа была разработана в рамках пакета прикладных программ Matlab R2015a с возможностью адаптации к конкретным задачам.

Ключевые слова: модель DEA, система нечеткой логики, опасные грузы, риск, предпочтительный маршрут.

ДЕФИНИСАЊЕ РИЗИКА НА ПУТНИМ ДЕОНИЦАМА ПРИ ТРАНСПОРТУ ОПАСНОГ ТЕРЕТА У ВОЈСЦИ СРБИЈЕ ПРИМЕНОМ МОДЕЛА ЛИНЕАРНОГ МАТЕМАТИЧКОГ ПРОГРАМИРАЊА

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ОБЛАСТ: математика, саобраћај, логистика
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У раду је представљен модел за избор руте, за транспорт опасног терета, употребом модела DEA (Data Envelopment Analysis) и fuzzy логичких система. Приказани модел се користи за дефинисање ризика на путним деоницама при транспорту опасног терета, као и за избор оптималне руте за реализацију транспортног задатка.

Методе: Модел се састоји од две фазе. У првој фази је примењена метода DEA која се састоји од два модела: импута и аутпута, повезана у излазни DEA final модел, који показује руте са задовољавајућим степеном безбедности саобраћаја и истовремено елиминише руте са ниским степеном безбедности саобраћаја. Друга фаза укључује примену fuzzy логичких система, а као излаз из fuzzy система дата је преференција према рути. Евалуација руте врши се на основу шест критеријума, а то су: дужина руте, број приступних тачака, ПГДС (просечан годишњи дневни саобраћај), број саобраћајних незгода са погинулим лицима, број саобраћајних незгода са повређеним лицима и број саобраћајних незгода са материјалном штетом. Када се унесу вредности улазних критеријума, врши се прорачун и евалуација, при чему се, као излаз из развијеног система, добија преференција према унетој рути (рута са најмањим нивоом ризика). Коришћени критеријуми дефинисани су на основу експертских процена.

Резултати: Кориснички програм користи се као подршка у одлучивању органима саобраћајне службе.

Закључак: Корисничка платформа креирана је у програмском пакету Matlab R2015а и пружа могућност надоградње и прилагођавања конкретном проблему.

Кључне речи: модел DEA, fuzzy логички систем, опасан терет, ризик, преференција према рути.

Paper received on / Дата получения работы / Датум пријема чланка: 25.01.2022.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 13.10.2022.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 14.10.2022.