Application of Cube IQ software and multicriteria optimization models for the selection of vehicles for the transport of goods in the Serbian Armed Forces

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Abstract:

Introduction/purpose: An adequate selection of vehicles used for the transport of goods is a very important factor that affects the economical and rational use of vehicle fleets, as well as the quality and efficiency of carrying out transport activities in the Serbian Armed Forces. The goal of this work is to design a model that should be of help to the traffic service authorities to select the vehicle that is best for the performance of the assigned transport task based on the defined criteria.

Methods: This paper therefore proposes a model for the selection of vehicles for the transport of goods using a fuzzy logic system, as a type of artificial intelligence system. In order to solve the problem of choosing a vehicle for the transport of goods, five criteria are defined in the work based on a survey of the commanders of the transport lines, which represent the input values in the fuzzy logic system.The vehicle is selected based on five criteria. The input variables are represented by three membership functions, while the output variable is defined by five membership functions. All the rules in the fuzzy logic system are determined using the rule premise weight aggregation method (ATPP), which enables the formation of a rule base based on experience. By applying this method and based on the number of input variables and the number of their membership functions, a base of 243 rules was defined. The values of the weighting coefficients of the membership functions were determined using the LMAW method. A user "interface" program was created for the developed fuzzy logic system, which enables the practical application of this model.

Results: The model was tested on the example of choosing the optimal vehicle for goods transported to the IVP "Pasuljanske livade" in 2020. The selection of the optimal means of transport was made among the transport *motor vehicles that are most used in the Serbian Army, namely: TAM 150 T11, FAP 2026 and FAP 1118. After packing all three vehicles with these goods in Cube IQ and after performing calculation and evaluation of individual vehicles in the user "interface" program, the values of the output variable for each vehicle were obtained. The obtained values for each vehicle were ranked and the optimal vehicle for the transport of defined goods was shown to be the FAP 1118.*

Conclusion: The significance of this study is that it is among the first ones to demonstrate the application of a model based on artificial intelligence that solves the problem of vehicle selection for the transportation of movable assets. The study provides considerable opportunity for further research.

Key words: fuzzy logic, fuzzy set, ATPP, LMAW, cube IQ, Matlab.

Introduction

Economical use of means of transport in peacetime is of great importance for the defense system of the Republic of Serbia. Transport motor vehicles with different usage characteristics are the basis of unit mobility. That is why it is important to choose the one that will best meet the set requirements from the large number of different types of motor vehicles that can be used to transport goods. A large number of different types of means of transport means that for every transport it is necessary to choose a motor vehicle that will perform a particular task best and most easily. Proper evaluation and selection of the right vehicle ensure the conditions for the efficient execution of the tasks set before the units of the Serbian Armed Forces. Taking into account the above, the choice of the optimal vehicle is of great importance for economical, successful and safe transport of units. In order to determine the optimal vehicle for the transport of goods for carrying out an assigned transport task, a choice must be made between the motor vehicles used in the Serbian Armed Forces. In order to facilitate the work of the traffic service authorities when choosing the optimal vehicle for the transport of goods, a model based on artificial intelligence is presented in the paper, in order to help solving that problem. Until now, the Serbian Army has not developed such a model that solves the problem of vehicle selection based on artificial intelligence.

Based on a survey of transport line commanders, several criteria were defined to represent the input variables in the fuzzy logic system, namely: number of transport vehicles, capacity utilization, motor vehicle reliability, fuel consumption per 100 km, and suitability for transport manipulative work. This is followed by the fuzzy system modeling through five stages: problem analysis, definition of linguistic variables, selection of membership functions, formation of the rule base, and selection of inference and defuzzification methods. For the developed fuzzy logic system, the user "interface" of the program for the selection of vehicles for the transport of goods was created in the Matlab 2017a program package.

The presented model was tested on the example of choosing the optimal vehicle for goods that were transported to the IVP "Pasuljanske livade" in 2020 for the needs of the Military Academy. The selection of the optimal means of transport was made from among the transport motor vehicles that are used the most in the Serbian Armed Forces, and these are TAM 150, FAP 2026, and FAP 1118. After packing the off-road vehicle TAM 150 with these goods in Cube IQ, we read the data from the software on how many motor vehicles we need to transport that type of goods and use the carrying capacity per vehicle. In order to unify the load capacity and obtain only one value, the arithmetic mean of all obtained values of the load capacity utilization of those vehicles was taken. In the same way, the packaging and obtaining the data necessary for the input variables in the fuzzy logic system is carried out for the off-road vehicles FAP 2026 and FAP 1118. The input value of fuel consumption per 100 km is obtained from the technical instructions for the mentioned motor vehicles, while the reliability of a motor vehicle and its suitability for transport manipulative work are obtained on the basis of the processed data from the survey of the commanders of the transport lines.

The defined input values are entered into the created user program and by starting the fuzzy system, the output variables are obtained, that is, the preference for the vehicle is obtained in the form of a numerical value and a linguistic descriptor. Based on the obtained values for each vehicle, a ranking was performed and the optimal vehicle for the transport of defined goods is the one with the highest preference value.

The paper consists of five parts. In the second part, the means of transport most commonly used in the army are mentioned. The third part presents the description and the method of designing the fuzzy logic system, as well as the display and the method of creating a user "interface" program for the selection of vehicles for transporting goods. Then the application of Cube IQ is defined. The fourth part deals with the data used when testing the modeled fuzzy system, a presentation of the use of Cube IQ and the method of obtaining the necessary parameters. Finally, concluding remarks with further research proposals are given.

Means of transport in the Serbian Army

In accordance with the Rulebook on the use of military vehicles in the Ministry of Defense and the Serbian Armed Forces, "a military vehicle is any combat and non-combat vehicle and any other vehicle that is registered under special regulations of the Ministry of Defense, as well as any other properly marked vehicle while performing material obligations in use in the units and institutions of the Ministry of Defense and the Serbian Army". According to this Rulebook, military vehicles are divided into:

- Non-combat motor vehicles of general purpose;
- Non-combat special purpose motor vehicles;
- Trailers;
- Combat vehicles;
- Engineering machines powered by liquid fuels;
- Special purpose vessels;
- Means of internal transport; and
- Other vehicles.

A general-purpose non-combat motor vehicle is a vehicle that, in accordance with its construction, devices and equipment, is intended for transporting people and cargo, for performing certain works, as well as for towing a trailer, while non-combat special-purpose vehicles represent vehicles that, by design, devices and assemblies, are intended and adapted for special purposes. Off-road non-combat vehicles, depending on their purpose and technical characteristics, can be divided into (Starčević, 2020):

- All-terrain vehicles for transporting people; and
- All-terrain vehicles for towing and transport.

The basic purpose of all-terrain vehicles for towing and transport in the Serbian Army is the transportation of people and cargo, towing tools and attachments, as well as the application for special superstructures of the cabin type. Constructive solutions of all-terrain vehicles allow the transportation of 12 to 20 people, while the carrying capacity of the vehicle ranges from 1.5 to 20 tons. All-terrain vehicles for towing and transport were mainly created on the basis of commercial vehicles, where the basic assemblies were modified to a greater or lesser extent for military use. Drive formulas for these vehicles are 4x2, 4x4, 6x6 and 8x8, depending on the total weight and load capacity of the vehicle. In the units of the Serbian Army, the following are mostly used: TAM 150, FAP 2026 and FAP 1118.

Off-road vehicle TAM 150 B/BV

The off-road vehicle TAM 150 T11 is a multi-purpose vehicle with all-wheel drive. This vehicle has great maneuverability and is designed so that it can be used in different weather, adverse road and terrain conditions. It is produced in variants:

- TAM 150 T11 BV – with winch; and
- TAM 150 T11 B – without winch.

The off-road vehicle TAM 150 T11 is intended for the transportation of personnel (18 + 2 persons), transport of loads up to 5t useful load on roads and up to 3t useful load off-road. Also, it can be used for towing tools, trailers, as well as for superstructures. This model of the off-road vehicle is in use in all units and institutions of the Serbian Armed Forces and its average age is over 30 years. Maintenance is difficult due to the lack of adequate spare parts, and therefore the degree of reliability of using the vehicle when performing daily tasks is reduced.

Figure 1 – All-terrain vehicle TAM 150 T11
Рис. 1 – Крупнотоннажный грузовой автомобиль ТАМ 150 Т11
Слика 1 – Теренско возило ТАМ 150 Т11

The dimensions of the off-road vehicle TAM 150 T11 are 6550mm x 2275mm x 2890mm, fuel consumption is 24 - 30 l/100km, while the dimensions of the cargo box are 4170mm x 2120mm x 1560mm (500mm) (Starčević, 2020).

Off-road vehicle FAP 2026

The all-terrain vehicle FAP 2026 is a domestically produced multi-purpose vehicle intended for driving on impassable terrain, transporting people (20 + 2 persons) with complete equipment, transporting material assets up to 10t useful load capacity on roads and up to 6t useful load capacity off-road, as well as for towing tools. Its dimensions are 7720mm x 2490mm x 3100mm, cargo box dimensions 4530mm x 2020mm x 1600mm (470mm), while fuel consumption is 33 l/100km (Starčević, 2020).

Figure 2 – All-terrain vehicle FAP 2026
Рис. 2 – Крупнотоннажный грузовой автомобиль ФАП 2026
Слика 2 – Теренско возило ФАП 2026

This model of all-terrain vehicle is used in the artillery and logistics units of the Serbian Army. The average age of the vehicle is over 20 years and the maintenance of these vehicles is regular due to the fact that the vehicle was produced in the Republic of Serbia and that the units of the Serbian Armed Forces have trained personnel and the necessary spare parts. It follows that the vehicles have an appropriate degree of reliability of use in the execution of everyday tasks.

Off-road vehicle FAP 1118

The all-terrain vehicle for towing and transport FAP 1118 was introduced to the Serbian Armed Forces in 2010 after successful development and final tests, and has been serially produced since 2012. This vehicle model was developed by a domestic manufacturer with the aim of renewing the vehicle fleet in the units of the Serbian Armed Forces and replacing the TAM 110 and TAM 150 vehicles. Its main purpose is to transport people with complete equipment (20 people), transport cargo up to 4t payload, tow tools and connecting devices, as well as application for special superstructures of the cabin type. The dimensions of the all-terrain vehicle FAP 1118 are: 6414mm x 2500mm x 3310mm, and the cargo box dimensions are 4000mm x 2440mm x 1720mm (550mm). Fuel consumption per 100km is 17-30l.

Figure 3 – All-terrain vehicle FAP 1118
Рис. 3 – Крупнотоннажный грузовой автомобиль ФАП 1118
Слика 3 – Теренско возило ФАП 1118

In the units of the Serbian Armed Forces, this vehicle is the newest and youngest all-terrain vehicle for towing and transport and is in use in the largest number of units and institutions of the Serbian Armed Forces, with a focus on logistics units. Vehicle maintenance is regular due to the fact that the vehicle is manufactured in the Republic of Serbia and that the units have trained personnel and the necessary spare parts, and therefore the vehicles have an appropriate level of reliability when performing daily tasks (Starčević, 2020).

Criteria for choosing a vehicle for transporting goods

The analysis came to the conclusion that there is no software based on artificial intelligence that is used for the selection of vehicles for the transport of goods in the Serbian Army. As a result of the research, the paper proposed a decision-making model, based on artificial intelligence, for the selection of vehicles for the transport of goods in the Serbian Armed Forces, and developed software for its practical application. For the selection of criteria for creating this model, the commanders of transport lines were surveyed. Based on the obtained data, the criteria for the selection of vehicles for the transport of goods were defined, which represent the input variables in the software. The criteria and their description are presented in the table.

Table 1 – Defined criteria for the selection of vehicles for the transport of goods in the Serbian Army
Таблица 1 – Определенные критерии выбора транспортных средств для перевозки грузов в сербской армии
Табела 1 – Дефинисани критеријуми за избор возила за транспорт робе у Војсци Србије

	Criterion	Description
1.	Number of means of transport	Required number of means of transport for transporting goods.
2.	Capacity utilization	The coefficient of static utilization of the vehicle's carrying capacity represents the ratio of the amount transported and the amount of cargo that could be transported, if the vehicle's carrying capacity were fully used while driving with the load.
3.	Motor vehicle reliability	The ability of the vehicle to carry out transport work, keeping its exploitation indicators at a given level during a certain time (mileage traveled) in given conditions of exploitation.
4.	Fuel consumption per 100 km	The amount of fuel used per 100 km of travel.
5.	Suitability for transport and manipulative work	Adaptation of the vehicle to loading and unloading processes, i.e., to enable loading or unloading with the least expenditure of time and labor, as well as optimal conditions for the goods.

A model for optimizing the choice of vehicles when transporting goods in the Serbian Armed Forces

The scheme of the model for optimizing the choice of vehicles when transporting goods in the Serbian Army is shown in Figure 4. In the first phase, after analyzing the problem, when modeling the fuzzy logic system, linguistic values are defined as well as the choice of membership functions, which allows us to form a rule base, and then select the inference and defuzzification method.

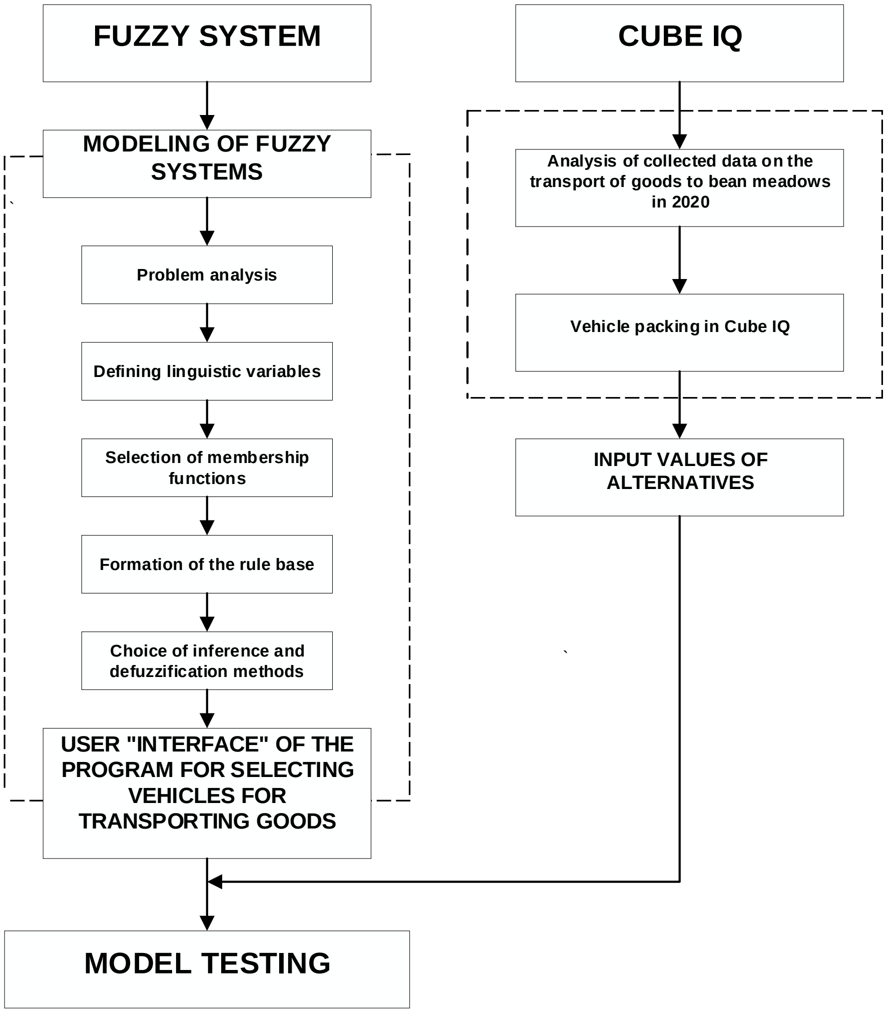

Figure 4 – Scheme of the model for the optimization of vehicle selection
Рис. 4 – Схема модели оптимизации выбора транспортных средств
Слика 4 – Шема модела за оптимизацију избора возила

After the completion of the first phase, in the next step, the user "interface" of the program is created, which allows us to apply this model in practice. In the second phase, by applying the Cube IQ software, based on the analysis of the collected data, the vehicle is packed, which allows us to define the input values of the alternatives that are inserted into the user form which performs model testing.

FUZZY systems

Artificial intelligence is defined as the branch of computer science that deals with the creation of computer programs capable of exhibiting "intelligent" behavior, one that is typically considered a uniquely human quality (Luger et al, 1994). The term "artificial intelligence" is widely used as the name of the branch of computer science that studies the ways in which computers can be made "smarter" (Raphael, 1976). Artificial intelligence as a scientific discipline deals with the method of automating intelligent behavior. It is based on learning from experimental data, learning from different patterns and transferring human knowledge to analytical models. The goal of this scientific discipline is the development and application of algorithms that will enable the computer to perform tasks in the way that the human brain performs them. Artificial intelligence methods are widely applied in all areas of solving engineering problems through (Zuber & Ličen, 2011):

- Expert systems - systems based on knowledge bases;
- Fuzzy logic systems - based on the transfer of human knowledge (experience) into the working system;
- Artificial neural networks - there are mathematical models behind the learning process; and
- Hybrid artificial intelligence systems – computer systems that integrate different intelligent techniques.

Words such as: vague, undefined, vague, imprecise, blurred, ambiguous, hazy could be replaced by one word - fuzzy. The founder of fuzzy logic is considered to be a professor of computer science at the University of California, Berkeley, whose name is Lofty Zadeh (Zadeh, 1975a; 1975b; 1975c). He laid the foundations of this science in 1965, and according to him, fuzzy logic can have two different meanings (Zadeh, 1965):

- In a broader sense, fuzzy logic is a synonym for the theory of fuzzy sets, and it refers to objects with unclear boundaries whose membership is measured by a certain degree; and
- In a narrower sense, fuzzy logic is a logical system that is an extension of classical logic.

The basis of his theory is that descriptions should be imprecise, which he shows by the principle of incompatibility, where he claims that by increasing the impreciseness of the statement, with which we describe the phenomenon, we increase its importance. A historically important element in the development and application of fuzzy logic is the first practical application, i.e. the first fuzzy regulator for controlling a steam engine, which was constructed by Mamandi and Assilian in 1974. In the 1990s, the market saw many products whose operation was based on the application of fuzzy logic. Today, it is a clear fact that fuzzy systems can be successfully applied in many areas: traffic management, stock exchange business, medical diagnostics, financial management, etc.

A set of elements with the same properties is called a classic discrete set and each element of a discrete set belongs to that set 100%, i.e. with a membership degree of 1 on a scale from 0 to 1. While fuzzy logic is based on the theory of fuzzy sets where the basic elements for representation and processing are imprecise, it represents an extension and generalization of a discrete set, that is, it represents a set of elements with similar characteristics where the membership of the elements can be any real number in the interval [0-1] (Zadeh, 1975a; 1975b; 1975c). The basic difference between these two types of sets is that classic sets always have a unique membership function, while fuzzy sets can be described with many different membership functions. A fuzzy set (A) can be defined as a set of ordered pairs.

$$\mathrm{A} = \{(x, \mu_A(\mathrm{x}))|\mathrm{x} \in \mathrm{X}\ , 0 \leq \mu_A(\mathrm{x}) \leq 1\ \} \qquad (1)$$

X is the universal set or set of considerations on which the fuzzy set A is defined, and μA (h) is the membership function of the element (h) of the set A (Puška et al, 2023). Each fuzzy set is completely and uniquely determined by its membership function. An element of a fuzzy set is every element in a confidence interval with a certain degree of membership, while the membership function is chosen based on the experience gained.

The confidence interval for each fuzzy variable is determined by the designer based on experience, observation or measurement. A confidence interval that is within the physical limits of the variable is most often adopted. A standardized value is adopted or an abstract confidence interval is defined (Božanić & Pamučar, 2014).

One of the features of fuzzy logic is that it is based on natural language where linguistic objects are words and not numbers. Linguistic expressions represent the connection between the numerical representation of information in a computer and the human way of thinking (Tešić et al, 2022).

So input and output variables can have different linguistic names which are displayed with descriptive names. The transformation of linguistic expressions into the form of a mathematical representation is made possible by the theory of fuzzy sets. In order to define linguistic variables more precisely, they should also have linguistic values, such as: "very little", "small", "medium", "large", "very large". These values can also be assigned a numerical representation for the purpose of easier and shorter marking.

Fuzzy relations are a natural extension of the concept of fuzzy sets and are used to represent relationships between elements that hold to a certain degree. In binary relations, two elements can either satisfy or not satisfy the relation, while in non-binary relations, the strength of the relation is expressed by expressions that express gradualness (Ćirović et al, 2014). In fuzzy relations, elements can have a higher or lower degree of belonging, which is expressed as a number from the interval [0,1].

Fuzzy proposition is a structure of the form "h is A", where the variable h and the set A are compared, that is, it determines the degree of belonging of the variable h to the fuzzy set A. Where variable h can be 0 or 1 or fuzzy 0.75. The combination of propositions and conjunctions creates a fuzzy rule that can be presented in the following form:

IF x is A

THEN y is B

Where x and y represent linguistic variables, and A and B linguistic values described by fuzzy sets with the confidence intervals X and Y. The conjunctions AND, OR, NOT, IF - THEN are used to connect propositions, which are quantified through T and S norms. The fuzzy rule describes a cause-and-effect relationship between input and output variables, while from the aspect of automation it represents a combination of sensor information and control actions.

Models based on fuzzy logic consist of "If - Then" rules that are connected by "Else" expressions. The first part of the If rule represents the input state, and the fuzzy proposition represents the premise, while the second part of the Then rule represents the output state, and the fuzzy proposition in this part represents the conclusion. A set of rules in which the solution to a problem is described in words is a rule base or expert rules. The rules are written in a convenient order for easier understanding and are connected by the conjunction Or (Else), which is often not stated (Pamučar, 2010).

In the relation, the input variables are most often represented by a number, while the output values are also obtained in numerical notation. Since the fuzzy system is described verbally (qualitatively) through production rules, it is necessary to convert (fuzzify) numerical values using fuzzy logical operations. After that, the mechanism of approximate reasoning (inference) processes them in the fuzzy system through three phases: aggregation, activation and accumulation (Pamučar et al, 2014).

The first step in solving a problem in fuzzy systems is fuzzification. It is a process that converts each numeric input into a membership degree. There is a degree of membership for each linguistic variable that applies to a particular physical quantity (Bozanić et al, 2019).

Aggregation is the stage in which the process of associating a certain value of the membership function with a measured numerical value is carried out, that is, it is determined with what degree of confidence some input numerical value belongs to a given fuzzy set. It is equivalent to phasing if there is only one input.

Activation is an inference made in the Then part of the rule and represents a deduction of the conclusion. The minimum and the algebraic product are used as the activation operator, as the most common methods of direct reasoning - Mamdani's method. In this type of reasoning, only true premises are taken into account. By applying this method, fuzzy sets are both input and output; this is important because another method is often used - the Takagi-Sugeno-Kang method. The difference between these two methods is in the structure of fuzzy rules, that is, in the conclusion, instead of a fuzzy set, there is a linear function of input and output.

Accumulation consists of activating the conclusion, which is accumulated by addition. The maximum or algebraic sum is used as an accumulation operator.

Defuzzification means converting the resulting fuzzy set into a real number. During mathematical defuzzification, information is reduced, because different values of the linguistic variable can be mapped into the same defuzzified real number. Therefore, it is necessary to be very careful when choosing a defuzzification method, because there is no method that is optimal for everyone. Also, one of the big problems is adjusting the fuzzy rule parameters in order to get the desired output. The adjustment methods are different and depend on the type of problem, because it is impossible to define a general methodology by which it is possible to perform the adjustment (Badi & Abdulshahed, 2021).

Models based on fuzzy logic generally require more iterations. In the first step, a set of rules and corresponding membership functions are defined, and then correction of individual rules and/or membership functions is performed, if necessary based on the observed results. Then the model is tested again.

Modeling fuzzy logic system

Based on the described system, the foundations were created to model the given system of interdependence of input criteria as a complex fuzzy system for the selection of vehicles for transporting goods. The final solution is reached through several stages, which in general modeling represent system design, optimization and application. All those stages in the fuzzy system can be specifically defined as:

– Problem analysis;
– Defining linguistic values;
– Selection of affiliation functions;
– Formation of the rule base;
– Choice of inference and defuzzification methods; and
– Application of fuzzy model.

Problem analysis

When modeling a fuzzy logic system, a detailed analysis of the problem is performed in order to determine the number of variables and their interdependence. If the problem is complex, the system is divided into several smaller subsystems, the goal and purpose of each subsystem is determined, and then the ways of connecting them and the priorities among them are defined.

Defining linguistic values

Linguistic variables, as already explained, take values from spoken language or are artificially synthesized. They are represented by fuzzy sets. It is thought that the designed fuzzy system, for the selection of vehicles for transporting goods, consists of five input linguistic variables:

– Number of means of transport;
– Utilization of carrying capacity;
– Reliability of the motor vehicle;
– Fuel consumption per 100 km;
– Suitability for transport and manipulative work;

and one output linguistic variable Vehicle Preference. The table shows the interval of linguistic variables that was used when designing the fuzzy system.

Table 2 – Interval of the input and output linguistic variables
Таблица 2 – Интервал входных и выходных лингвистических переменных
Табела 2 – Интервал улазних и излазних лингвистичких променљивих

Input linguistic variables	Interval	
	from	to
Number of means of transport	1	8
Capacity utilization	0	1
Motor vehicle reliability	0	10
Fuel consumption per 100 km	0	40
Suitability for transport and manipulative work	0	10
Output linguistic variable	Interval	
	from	to
Vehicle preference	0	1

After defining and determining the interval of linguistic variables, it is necessary to determine the number and type of membership functions for all input and output variables. Setting up the system complicates a larger number of membership functions, and, cosequently, a larger number of rules, so it is recommended to start with reducing the number of membership functions in accordance with the nature of the variable (Krstić, 2006). This reduction must not be done if there is a change in the quality of the variable. Therefore, it is defined that in the model each input variable has three membership functions, while the output variable has five membership functions. The linguistic values of all input variables are: Small, Medium, Large, while the output linguistic values are: Very Small, Small, Medium, Large and Very Large.

Since it is a decision support system, a large number of linguistic variables was not needed. With three linguistic values, a satisfactory gradualness in changing the output values was achieved, which maximized the number of rules to 243, which is within the range that an expert can control.

Selection of membership functions

The choice of membership functions and their range is an important stage when modeling a fuzzy logical system. In the fuzzy system, Gaussian curves were used, since they describe the input and output variables well and enable optimal sensitivity of the system (Vesković et al, 2020). Figure 5 shows the membership functions of the input linguistic variables, while Figure 6 shows the membership function of the output variable.

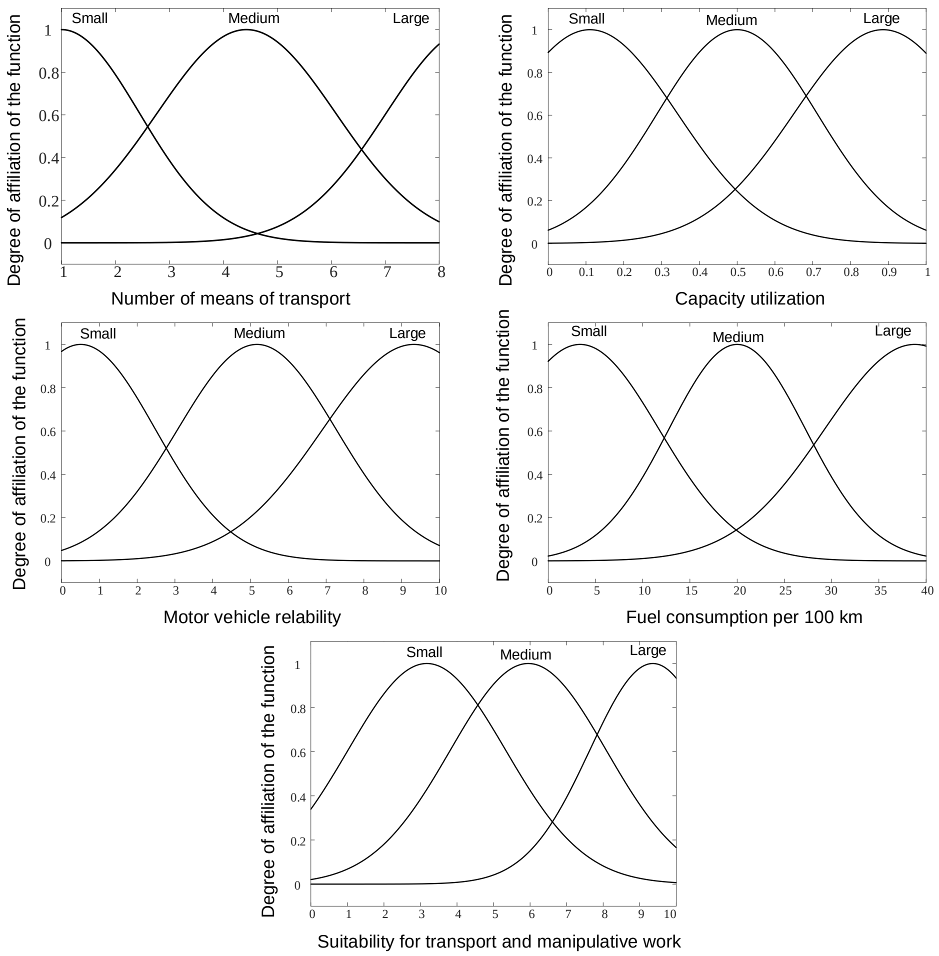

Figure 5 – Membership functions of the input linguistic variables
Рис. 5 – Функции принадлежности входных лингвистических переменных
Слика 5 – Функције припадности улазних лингвистичких променљивих

The values of membership functions of input and output variables are shown in Table 3, where the first number in the interval represents the left and right distribution of the Gaussian curve along the abscissa, and the second number represents the value in which the Gaussian curve has a value of 1 on the abscissa axis.

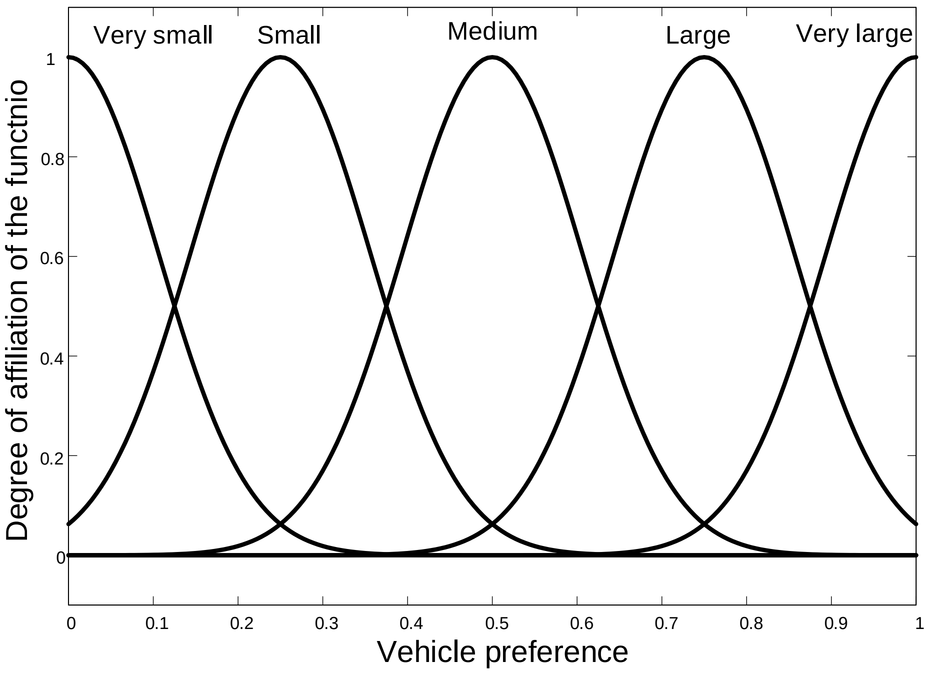

Figure 6 – Membership functions of the output variable
Рис. 6 – Функции принадлежности выходной переменной
Слика 6 – Функције припадности излазне променљиве

Table 3 – Values of the membership functions of the input variables
Таблица 3 – Значения функций принадлежности входных переменных
Табела 3 – Вредности функција припадности улазних променљивих

Membership function/ Input value	Small	Medium	Large
Number of means of transport	[1.45 , 1]	[1.66 , 4.428]	[1.58 , 8.59]
Capacity utilization	[0.232 , 0.1104]	[0.2119 , 0.5]	[0.236 , 0.8859]
Motor vehicle reliability	[1.98 , 0.5074]	[2.1 , 5.169]	[2.42 , 9.3]
Fuel consumption per 100 km	[8.37 , 3.38]	[7.254 , 20]	[9.575 , 38.8]
Suitability for transport and manipulative work	[2.16 , 3.174]	[2.136 , 5.95]	[1.728 , 9.36]

Formation of the rule base

The rule base is composed of a certain number of rules, expressed in spoken or artificial language words, which represent the expert's knowledge. A big problem with complex systems is that there is no standard and systematic method for transforming engineering knowledge or experience into fuzzy rules. As already mentioned, there is also no general procedure for choosing the optimal number of rules, since many factors influence such a decision.

At the beginning, for each combination of the input linguistic variable, the expert suggests the corresponding output value. As already mentioned, the system consists of five input linguistic variables (n=5) with three linguistic values each (M=3) that can be combined in a database with a total of M^n=3^5=243 rules. In the paper, to determine the rules of the fuzzy logical system, the "Method of Aggregation of Rule Premise Weights" (ATPP) was used. The ATPP method for determining the rule base consists of six steps (Ćirović & Pamučar, 2013):

– Determination of the weight coefficients of the input variables;
– Determination of the type (type) and function numbers of the input - output variables;
– Determination of the weighting coefficients of the membership functions of the input variables;
– Generation of the initial (incomplete) rule base with the maximum number of combinations of input - output pairs;
– Generating a "complete" rule base by assigning appropriate conclusions $(y_i^{(r)})$to premises $(x_i^{(j)})$; and
– Optimization of rules.

At the beginning, the weighting coefficients of the relevance functions $(w_{x_i}^{(j)})$ of the input variables are determined, usually based on the subjective assessment of the expert who models the fuzzy logic system. In addition, the weight coefficients of the membership function can be determined by group decision-making or aggregation of expert decisions (Kiptum et al, 2022).

The distribution of weight coefficients can be even or uneven, but it should reflect reality as much as possible. In the specific case, it was defined with the help of the LMAW method based on a questionnaire. An overview of the LMAW method is given in (Pamučar et al, 2021). The value of the weight coefficients is given in Table 4.

Table 4 – Weighting coefficients of criteria
Таблица4 – Весовые коэффициенты критериев
Табела 4 – Тежински коефицијенти критеријума

Criterion	Weight coefficient of criteria	$w_{x_i}^{(1)}$	$w_{x_i}^{(2)}$	$w_{x_i}^{(3)}$
K1 (number of means of transport)	0.229	0.229	0.114	0.05
K2 (capacity utilization)	0.207	0.05	0.103	0.207
K3 (motor vehicle reliability)	0.247	0.06	0.123	0.247
K4 (fuel consumption per 100 km)	0.178	0.178	0.11	0.04
K5 (suitability for transport and manipulative work)	0.138	0.03	0.09	0.138

An initial "incomplete" rule base is then generated with the maximum number of combinations that can combine the membership functions. The initial base of rules contains only premises (the "If" part of the rule), that is, combinations of all membership functions of the input variables of the fuzzy logic system ($x_i^{(j)}$). The initial "incomplete" rule base (R) is displayed in a matrix form as:

$$R = \begin{array}{c} \\ R_1 \\ R_2 \\ \vdots \\ R_c \end{array} \begin{array}{c} \begin{array}{cccc} X_1 & X_2 & \dots & X_n \end{array} \\ \begin{pmatrix} x_1^{(1)} & x_2^{(1)} & \dots & x_n^{(1)} \\ x_1^{(2)} & x_2^{(1)} & \dots & x_n^{(2)} \\ \vdots & \vdots & \dots & \vdots \\ x_1^{(m)} & x_2^{(m)} & \dots & x_n^{(m)} \end{pmatrix} \end{array} \tag{2}$$

where $x_1^{(p)}, \dots, x_n^{(q)}$ is the membership function of the input variables $X_1, \dots, X_n$.

Then the matrix R' is constructed in which the combinations of input pairs are replaced by the weight coefficients ($w_{x_i}^{(j)}$).

$$R' = \begin{pmatrix} w_{x_1}^{(1)} & w_{x_2}^{(1)} & w_{x_3}^{(1)} & \dots & w_{x_n}^{(1)} \\ w_{x_1}^{(2)} & w_{x_1}^{(2)} & w_{x_3}^{(2)} & \dots & w_{x_n}^{(2)} \\ w_{x_1}^{(3)} & w_{x_2}^{(3)} & w_{x_3}^{(3)} & \dots & w_{x_n}^{(3)} \\ \dots & \dots & \dots & \dots & \dots \\ w_{x_1}^{(m)} & w_{x_2}^{(m)} & w_{x_3}^{(m)} & \dots & w_{x_n}^{(m)} \end{pmatrix} \tag{3}$$

After forming the matrix R', the elements of the matrix are summed up by rows:

$$w_j = \sum_{j=1}^{n} w_{x_i}^{(j)} \, y^+, y^+ \in [y^-, y^+] \,\& \tag{4}$$

where y^{+} represents the upper limit of the confidence interval $[y^{-}, y^{+}]$ of the output variable Y. Then it is necessary to determine the degree of the membership of the real number w_j to the membership function $y^{(r)}$ of the output variable Y.

$$y^{(r)} = \max(w_y \cap \mu_{y^{(r)}}) \tag{5}$$

in order to generate the rule base, it is necessary at the beginning that each pair of the membership function ($x_i^{(i)}$) of the input variables (X_i) is associated with the corresponding membership function ($y^{(r)}$) of the output variable (Y). That is why redundant rules are eliminated in order not to burden the system, especially when there are several rules that have similar or the same combinations of the membership functions of input/output variables. When this happens, the rule that has the largest sum of the weight coefficients of the membership functions contained in the rule is left, namely:

$$R = \max \sum w_{x_R}^{(i)}, i = 1,2,\ldots,n \tag{6}$$

If we define that:

- A - number of means of transport
- B - capacity utilization;
- C - motor vehicle reliability;
- D - fuel consumption per 100 km;
- E - suitability for transport and manipulative work; and
- F – vehicle preference;

then an example rule reads:

IF (A is Small) **AND** (B is Small) **AND** (C is Medium) **AND** (D is Small) **AND** (E is Large) **THEN** (F is Very Small).

By entering numerical values into the fuzzy system, different values of the input variables are set and the value of the output variable Preference according to the vehicle is controlled.

Choice of inference and defuzzification method

The most frequently used methods in direct inference are MIN-MAX and PROD-SUM (Mamdani method). At the beginning of this phase, the MIN-MAX method was used and it is used when it is not important to manage the entire confidence interval of the output variable. In a large number of system simulations, this method proved unsuitable. One of the basic requirements was to achieve a satisfactory level of system sensitivity, which cannot be achieved using this method. The desired shape could not be obtained with the settings, and even if it was achieved, it would only be valid for certain values of the input variables. By changing the parameters, the surface would appear even less acceptable, and therefore the system would be even less sensitive (Milošević et al, 2021). Therefore, the method of direct inference was used - PROD-SUM as the best one offered by the Matlab program package.

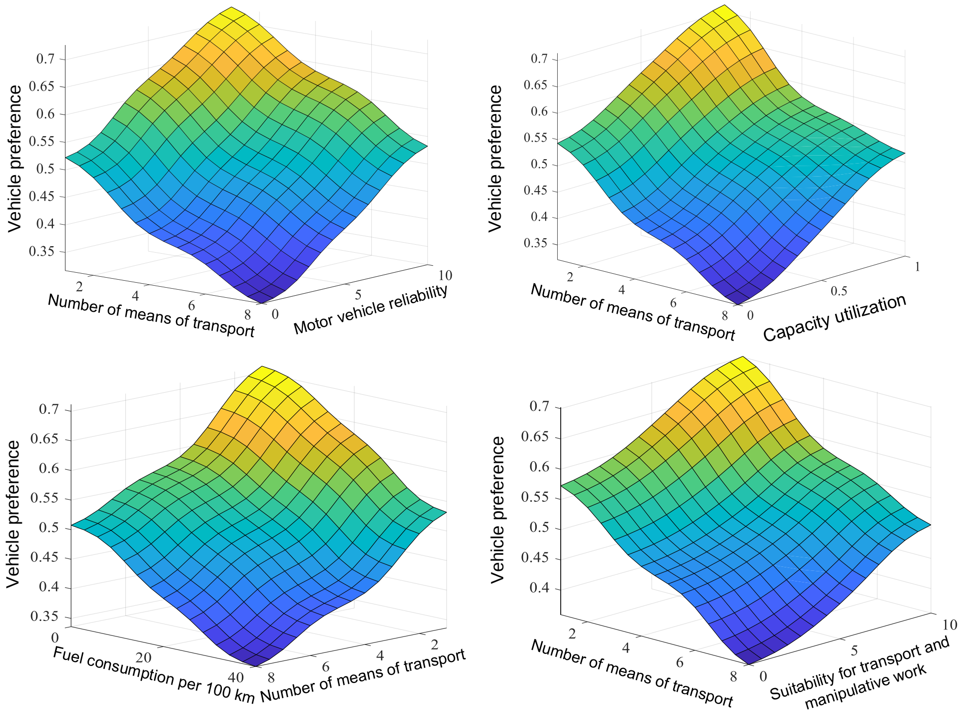

Figure 7 – Interdependence of the solution and two input variables by the PROD-SUM method

Рис. 7 – Взаимозависимость решения и двух входных переменных при применении метода PROD-SUM

Слика 7 – Међузависност решења и две улазне променљиве применом методе ПРОД-СУМ

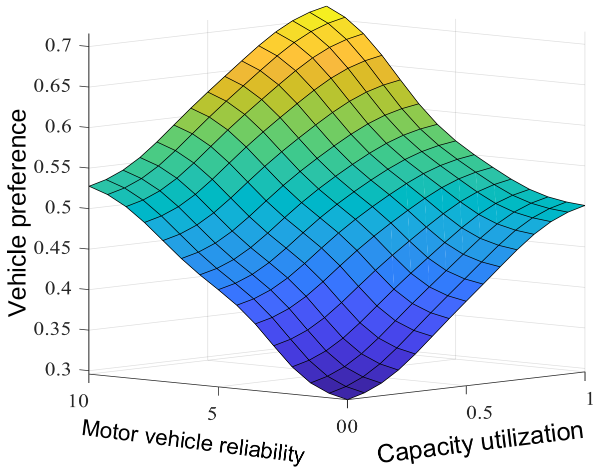

Figure 8 – Interdependence of the solution and two input variables by the PROD-SUM method
Рис. 8 – Взаимозависимость решения и двух входных переменных при применении метода PROD-SUM
Слика 8 – Међузависност решења и две улазне променљиве применом методе ПРОД-СУМ

The difference between the MIN-MAX and PROD-SUM methods is that in the activation phase of the fuzzy rule according to the MIN-MAX method, cutting is performed, in fact only the activated parts of the fuzzy sets are taken into account, and with the PROD-SUM method, scaling is performed - proportionally reduction. Activation of the conclusion by the MAX method accumulates the union of two phase sets, while the accumulation contours by the SUM method are obtained as an algebraic sum. At the beginning of the inference process, the values of the input variables are phased. During the fuzzification process, the membership functions defined for the input variables are applied to the actual value of the input variable to determine the degree of membership for the premise of each of the rules in the database. After this, the expert system performs an analysis in accordance with the previously defined limits, which represent the membership functions of individual variables. Each linguistic variable consists of multiple fuzzy sets and the goal of fuzzification is to determine which fuzzy set "belongs" to each input variable and to represent that membership with a numerical value located in the interval [0,1]. After phasing the input variables, those values are analyzed and compared with the sets of premise values from the rule base. In order for all conditions to be satisfied, a smaller value is taken, i.e. the intersection of fuzzy sets, due to the use of the operator "and" between the elements. Then the obtained value is transferred to the fuzzy set which represents the conclusion.

User "interface" of the program for selecting vehicles for transporting goods

For the developed fuzzy logic system, the user "interface" of the program for the selection of vehicles for the transport of goods was created in the Matlab 2017a program package. By entering "T" in the command line of the program package, the home page of the user program for the selection of vehicles for the transport of goods in the Serbian Armed Forces is launched.

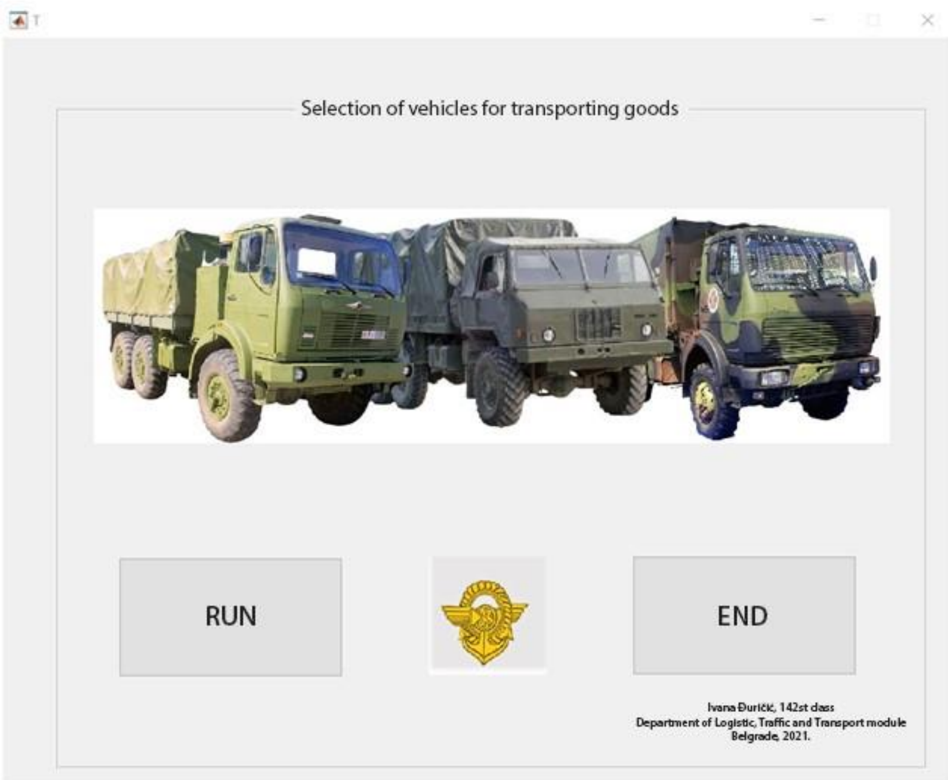

Figure 9 – Home page of the user form
Рис. 9 – Главная страница пользовательской формы
Слика 9 – Почетна страна корисничке форме

Pressing the "RUN" button opens the fuzzy logic model. In the "Entry to fuzzy system" part of the user form, the user enters the desired values in the empty field below the defined criteria, while the interval values are below the empty field.

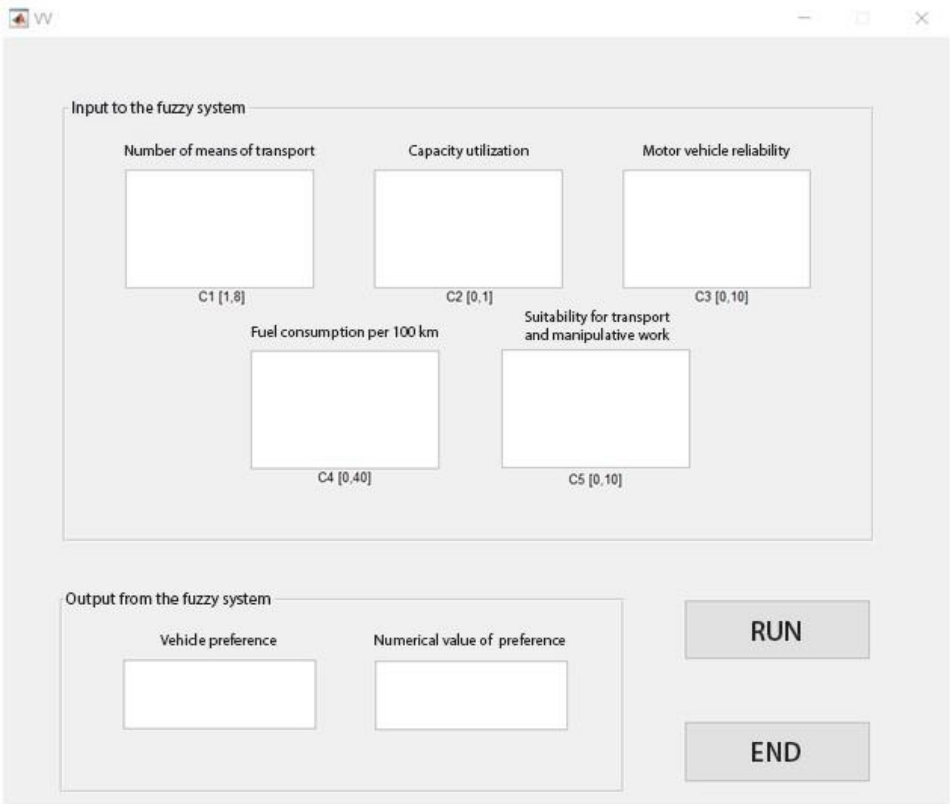

Figure 10 – A model for entering input values into the system and displaying output values from the fuzzy logic system.
Рис. 10 – Модель ввода входных значений в систему и отображения выходных значений из системы нечеткой логики.
Слика 10 – Модел за уношење улазних вредности у систем и приказ излазних вредности из fuzzy логичког система

Upon completion of identification, the user closes the user form by pressing the "END" button, after which the program returns him to the initial page of the user interface for vehicle selection, and closing the interface is also done by pressing the "END" button.

Cube IQ

Cube IQ is software designed for optimal packing of containers, trucks, pallets, crates and boxes. This software is unique in that, in addition to regular shaped containers, it can also pack irregularly shaped containers, such as air containers (ULD - Unit Load Device). It can also determine the position of the center of gravity, pack loads in the form of rolls, and optimize multiple containers/trucks at the same time. The great advantage of this software is that there is no limit to the number of trucks during optimization, as well as the possibility of obtaining certain parameters (capacity utilization coefficient, volume utilization coefficient) when packing vehicles with goods of different sizes. How to use Cube IQ software is covered in (MagicLogic Optimization Inc, 2004)

The work uses Cube IQ software for packing off-road vehicles TAM 150, FAP 2026, and FAP 1118. From the software, we get data on the number of vehicles and utilization of payload and use these values for input variables in the fuzzy logic system. In the next chapter, the application of Cube IQ, as well as the designed fuzzy system, will be described.

Model testing

Practical application is a logical phase in the life cycle of the model. The model should be applied and, if necessary, certain corrections, changes, and improvements should be made again, which is relatively easy in the fuzzy system (Pamučar at al, 2016). The confidence intervals of the input variables as well as the output variables can be changed and adapted to the circumstances in which the program will be used. The interval [0,1] was taken for the confidence interval of the output variable Preference towards the vehicle.

To test the described model, data were used on the goods transported in 2020 to the Intervidov Polygon (IVP) of "Pasuljanske livade" for the needs of the Military Academy. For the transport of these goods, the vehicle optimal for the task is selected using the designed fuzzy logic system. During the selection process, three vehicle types used in the Serbian Armed Forces, already mentioned in the paper, were considered. The input values for Number of transport means and Capacity utilization are obtained from Cube IQ, Fuel consumption per 100 km is obtained from the technical manual for the mentioned motor vehicles, while Motor vehicle reliability and Suitability for transport manipulative work are obtained based on the data processed from the survey.

Data analysis

Data were collected on dangerous goods transported to the IVP "Pasuljanske livade" in 2020 for the needs of the Military Academy. These data represent the input values to Cube IQ software, after which the vehicle to be packed is selected. At the same time, how this software works is shown and data are obtained to be used when testing the fuzzy system, i.e. for the selection of vehicles that would be optimal to use when transporting dangerous goods to the IVP "Pasuljanske livade" in 2020.

Table 5 – Data on goods transported in 2020 at the IVP "Pasuljanske livade"
Таблица 5 – Данные о товарах, перевезенных в 2020 году на ИВП "Пасулянске ливаде"
Табела 5 – Подаци о роби која је транспортована 2020. године на ИВП „Пасуљанске ливаде"

IVP "Pasuljanske livade" 2020. years	Box dimensions			Carrying capacity of the crate (kg)	Amount of crates transported
	l (m)	b (m)	h (m)		
Bullet 12, 7mm regular grain M09	0.37	0.33	0.21	34	11
Bullet 5.56 mm with ordinary grain M03 and MČ P-1800	0.555	0.315	0.14	28.5	60
Bullet 7.62mm, T.Z. M30 MCH P-1200	0.5	0.3	0.18	38	40
Bullet 7.62mm for PKT, ordinary grain M908, ch.ch (s), R	0.44	0.29	0.2	40	40
Bullet 7.9mm, UNIV.Z.MČ.PB-900 for sniper rifle	0.44	0.36	0.22	45	15
RBR 64 mm M80 -Zolja-	0.965	0.32	0.27	25	1
Bullet 7.62mm marking grain T-46	0.48	0.35	0.16	26	27
Bullet 12.7mm MC BZT (S) P288 DSKM	0.5	0.315	0.2	48	1
Signal bullet 26mm	0.49	0.33	0.39	48	9
Mine 120mm LTF	0.71	0.35	0.22	43	1
Bullet 152mm TFP	0.95	0.46	0.24	95	169
Mine 82mm M74	0.55	0.52	0.27	46	4
Capsule No. 8	0.44	0.21	0.03	20	1
Caps ek 40-69	0.38	0.3	0.29	18	1
Detonating stick, PVC insulated	0.78	0.24	0.24	22	1
Slow-burning stick	0.61	0.3	0.33	22	1
Bullet TM-200 B.G.	0.57	0.25	0.19	27	1

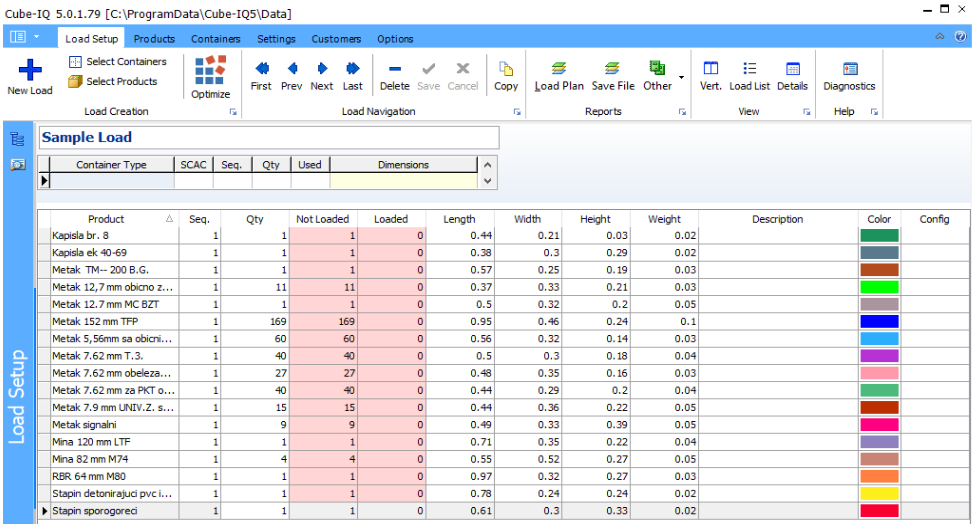

Figure 11 – Entry of goods input into Cube IQ
Рис. 11 – Ввод товарных данных в Cube IQ
Слика 11 – Унос улазних података о роби у Cube IQ

Before selecting a vehicle, it is necessary to enter the basic vehicle data into the software and these data are shown in Table 6, while Figure 12 shows how the data entry in Cube IQ looks like.

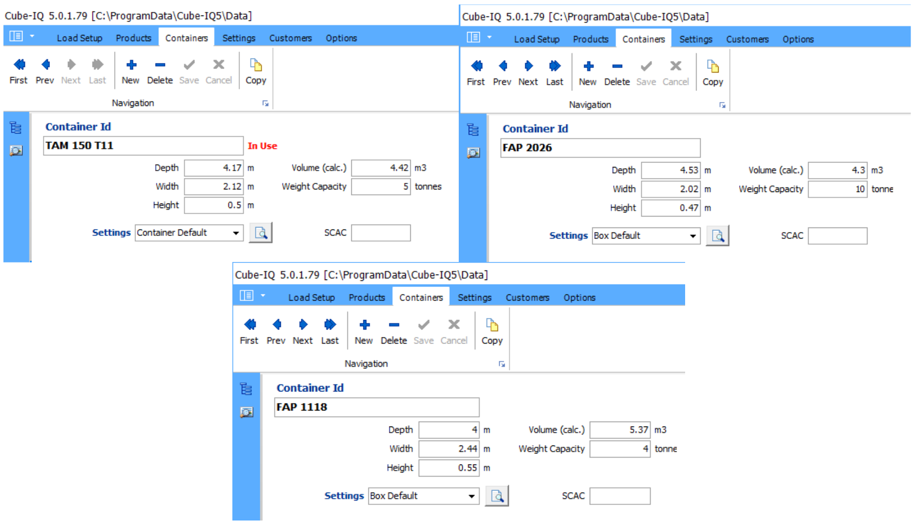

Figure 12 – Entering vehicle data into Cube IQ
Рис. 12 – Ввод данных о транспортых средствах в Cube IQ
Слика 12 – Унос података о возилима у Cube IQ

Table 6 – Basic data about vehicles that are entered into Cube IQ

Таблица 6 – Основные данные о транспортных средствах, которые вводятся в Cube IQ

Табела 6 – Основни подаци о возилима који се уносе у Cube IQ

Off-road vehicle	Dimensions of the cargo box of the vehicle			Vehicle load capacity (t)
	L (m)	B (m)	H (m)	
TAM 150 T11	4.17	2.12	0.5	5
FAP 2026	4.53	2.02	0.47	10
FAP 1118	4	2.44	0.55	4

Vehicle packing

After entering all the necessary data, the packing of the off-road vehicle TAM 150 T11 was carried out, by selecting the vehicle from the database and by calling the "Optimize" option, the packing of the vehicle begins, while at the end the packing plan of the vehicle is obtained.

Figure 13 shows the entire process in Cube IQ.

Once the vehicle packing plan has been obtained, the required data are read. Thus, 6 TAM 150 T11 all-terrain vehicles are needed for the transport of goods, while the capacity utilization is shown per vehicle. In order to unify it and obtain only one value, the arithmetic mean of all obtained values of the load capacity utilization of those vehicles was taken.

$$\bar{\gamma} = \frac{\sum_{i=0}^{n} \gamma_i}{n} \qquad (7)$$

In the same way, the packaging and obtaining the data, necessary for the input variables in the fuzzy logic system, are carried out for the off-road vehicles FAP 2026 and FAP 1118. So, 7 FAP 2026 vehicles and 6 FAP 1118 vehicles are needed.

Table 7 shows utilization of carrying capacity by vehicles, as well as the final value obtained on the basis of formula (7).

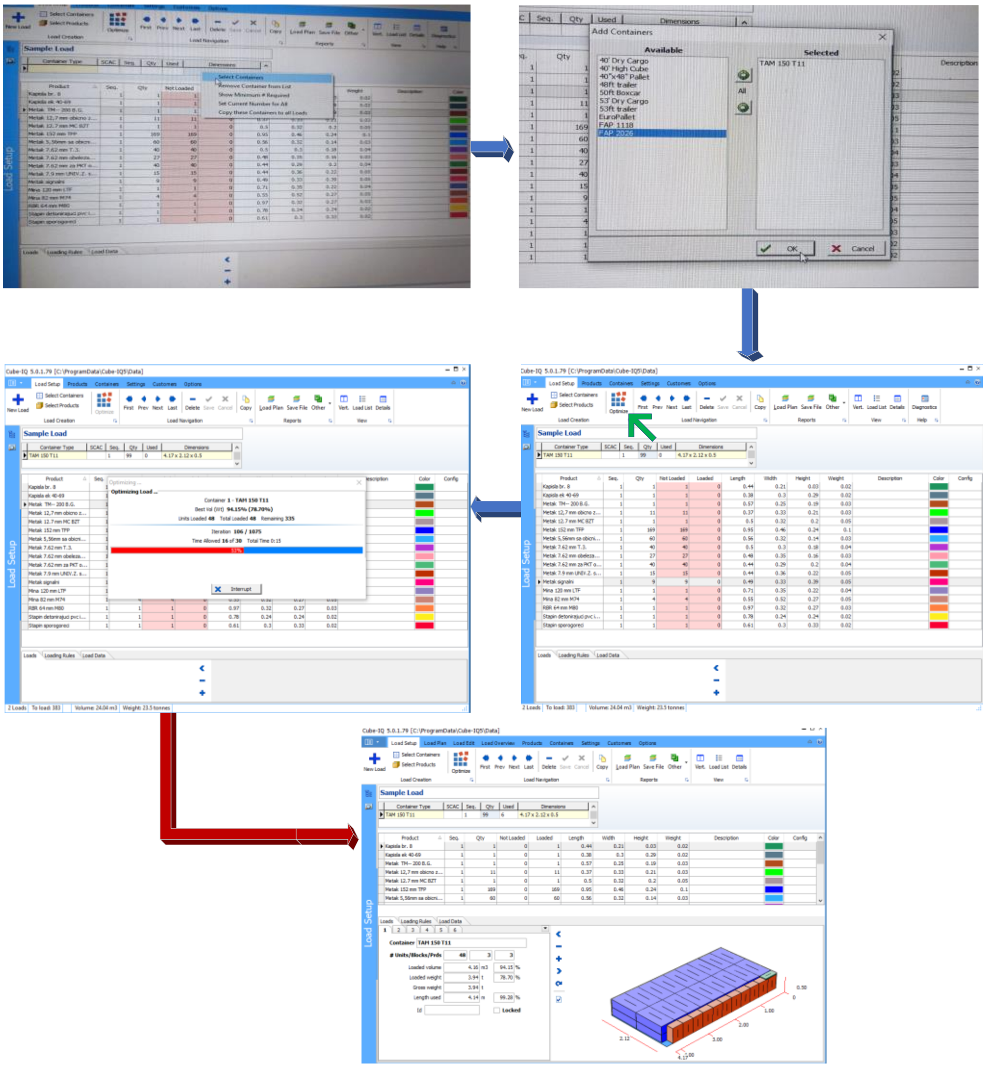

Figure 13 – Procedures for selecting a vehicle and packing it in Cube IQ

Рис. 13 – Процедуры выбора транспортного средства и его погрузки в Cube IQ

Слика 13 – Поступци приликом избора возила и његовог паковања у Cube IQ

Table 7 – Utilization of the vehicle's carrying capacity
Таблица 7 – Использование грузоподъемности транспортного средства
Табела 7 – Искоришћење носивости возила

		Off-road vehicle		
		TAM 150 T11	FAP 2026	FAP 1118
	Number of means of transport (n)	6	7	6
Capacity utilization	Vehicle 1 (γ_1)	0.787	0.4313	0.9985
	Vehicle 2 (γ_2)	0.7508	0.44	0.9985
	Vehicle 3 (γ_3)	0.7508	0.361	0.999
	Vehicle 4 (γ_4)	0.7508	0.361	0.999
	Vehicle 5 (γ_5)	0.9396	0.361	0.999
	Vehicle 6 (γ_6)	0.7224	0.3647	0.8815
	Vehicle 7 (γ_7)	/	0.317	/
	Final value of payload utilization ($\bar{\gamma}$)	0.78	0.38	0.98

Table 8 summarizes the defined values of the input variables in the fuzzy logic system for each vehicle and these parameters are entered into the user program.

Table 8 – Values of the input variables in the fuzzy system
Таблица 8 – Значения входных переменных в нечеткой системе
Табела 8 – Вредности улазних променљивих у fuzzy систему

	Number of means of transport	Capacity utilization	Motor vehicle reliability	Fuel consumption per 100 km	Suitability for transport and manipulative work
TAM 150 T11	6	0.78	6	24	7
ФАП 2026	7	0.38	8	33	8
ФАП 1118	6	0.98	9	23.5	9

After entering the values into the user program and starting the fuzzy system, the output values shown in Figure 14 are obtained, after which they are entered in Table 9.

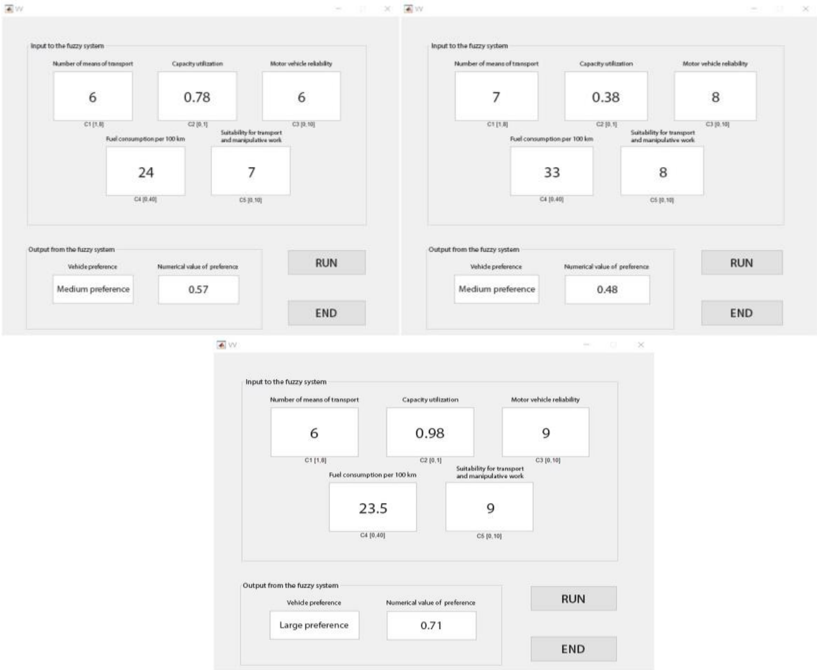

Figure 14 – Display of the output values from the fuzzy system
Рис. 14 – Отображение выходных значений из нечеткой системы
Слика 14 – Приказ излазних вредности из fuzzy система

Table 9 – Output values from the fuzzy system - Vehicle preference
Таблица 9 – Выходные значения из нечеткой системы - Предпочтение транспортного средства
Табела 9 – Излазне вредности из fuzzy система – преференција према возилу

VEHICLES	VEHICLE PREFERENCE	
	Preference	The numeric value of the preference
TAM 150 T11	Medium preference	0.57
FAP 2026	Medium preference	0.48
FAP 1118	Large preference	0.71

Based on the results obtained, the optimal vehicle for carrying out the transportation of goods to the IVP "Pasuljanske livade" is FAP 1118. The vehicle ranking can be shown as FAP 1118 > TAM 150 T11 > FAP 2026.

Conclusion

In the life and work of the units, there are daily needs to transport large quantities of various goods. For the execution of these tasks, military vehicle fleets are used, mainly for transport on shorter distances, while for longer distances, the vehicles of transport organizations are used most often. In this regard, more and more attention is being paid to the economical, that is, rational use of the vehicle fleet. One of such methods is centralized transport, which has not yet been fully implemented in the Serbian Army. This paper presents a proposal for choosing the optimal motor vehicle for the transport of mobile assets in the Serbian Army, all with the aim of facilitating the work of the traffic service authorities in planning the transport of mobile assets.

The selection of vehicles for the transport of movable assets was carried out using a fuzzy logic system, which belongs to the group of models based on artificial intelligence.

There are a large number of different types of motor vehicles in the Serbian Army, and it is not easy to define which type of vehicle is optimal for the delivery of mobile assets. Each unit and institution of the Ministry of Defense and the Armed Forces has a different organizational and formation structure, and therefore different needs related to support.

The basis for solving the problem of choosing a vehicle for transporting goods is the correct definition of the criteria and their relative importance. By surveying the commanders of transport lines, five criteria were defined in this paper, which represent the input values of the fuzzy logic system. The selected criteria are: number of means of transport, capacity utilization, motor vehicle reliability, fuel consumption per 100 km and suitability for transport manipulative work. To date, no motor vehicle has been made that can satisfy all criteria simultaneously in their optimal sizes, but overall, based on all these criteria, the most favorable should be selected with the help of a fuzzy system. The output variable is represented as vehicle preference.

The input variables are represented by three membership functions, while the output variable is defined by five membership functions. For the membership functions of the input and output variables, Gaussian bell functions were used, due to the requirement that there is a certain degree of sensitivity of the system. All the rules in the fuzzy logic system are determined by applying the rule premise weight aggregation method (ATPP), which enables the formation of a rule base based on experience. By applying this method and based on the number of input variables and the number of their membership functions, a base of 243 rules was defined. The values of the weighting coefficients of the membership functions were determined using the LMAW method. In order to increase the sensitivity of the system as an inference method, the PROD-SUM method was used.

The presented model was tested on the example of choosing the optimal vehicle for the goods transported to the IVP "Pasuljanske livade" in 2020. The selection of the optimal means of transport was made between the transport motor vehicles that are most used in the Serbian Army, namely: TAM 150 T11, FAP 2026 and FAP 1118.

After packing all three vehicles with these goods in Cube IQ, the values of the input parameters for the fuzzy logic system were obtained, for the criteria of the number of means of transport and the utilization of carrying capacity. After the calculation and evaluation of the individual vehicles, the values of the output variable of the fuzzy logic system were obtained in the user "interface" program, that is, the preference for the vehicle was obtained, in the form of a numerical value and a linguistic descriptor. The obtained values for each vehicle were ranked and the optimal vehicle for the transport of defined goods was shown to be the FAP 1118.

The significance of this work is that it is among the first ones to demonstrate the application of a model based on artificial intelligence that solves the problem of vehicle selection for the transportation of movable assets. The work provides great opportunities for further research.

In this sense, further research is needed to establish the criteria that are crucial for the transport of goods in the army. Next, one should determine the intervals that the input variables will cover and properly divide them into the required number of parameters. In this way, the number of criteria and the interval values of the input variables would be adapted to a real situation and this model could be included in the daily work of the traffic service authorities.

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Применение программного обеспечения Cube Iq и многокритериальной модели оптимизации при выборе транспортных средств для перевозки грузов в Вооруженных силах Республики Сербия

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

Резюме:

Введение/цель: Правильный выбор транспортных средств, используемых для перевозки грузов, является важным фактором, влияющим на экономичное и рациональное использование автопарков, а также на качество и эффективность осуществления транспортной деятельности в Вооруженных силах Республики Сербия. Целью данной статьи является разработка модели на основании определенных критериев, которая поможет органам транспортной службы выбрать наиболее подходящее транспортное средство для выполнения поставленной транспортной задачи.

Методы: В данной статье предлагается модель выбора транспортных средств для перевозки грузов с использованием системы нечеткой логики как разновидности системы искусственного интеллекта. Для того чтобы решить проблему выбора транспортного средства для перевозки грузов, в статье на основе опроса командиров транспортных взводов были определены пять критериев, которые представляют входные значения в системе нечеткой логики. Транспортное средство выбирается на основе пяти критериев. Входные переменные представлены тремя функциями принадлежности, в то время как выходная переменная определяется пятью функциями принадлежности. Все правила в системе нечеткой логики определяются с помощью метода агрегирования подусловий в нечетких правилах, который позволяет сформировать базу правил на основании опыта. Благодаря данному методу, а также количеству входных переменных и функций принадлежности к ним, была определена

база из 243 правил. Значения весовых коэффициентов функций принадлежности были определены с помощью метода LMAW. Для разработанной системы нечеткой логики была создана программа пользовательского интерфейса, которая позволяет применять эту модель на практике.

Результаты: Модель была протестирована на примере выбора оптимального транспортного средства для перевозки грузов на ИВП "Пасулянске ливаде" в 2020 году. Выбор оптимального транспортного средства был сделан на основании транспортных средств, которые наиболее часто используются в сербской армии, а именно: ТАМ 150 Т11, FAP 2026 и FAP 1118. После погрузки грузов во все три вида транспортных средств в Cube IQ и после выполнения расчета и оценки отдельных транспортных средств в пользовательской "интерфейс" программе были получены значения выходной переменной по каждому транспортному средству. На основании ранжирования полученных значений всех видов транспортных средств выявлено, что оптимальным транспортным средством для перевозки определенных грузов является FAP 1118.

Выводы: Значимость данного исследования заключается в том, что оно одним из первых продемонстрировало применение модели, основанной на искусственном интеллекте, которая решает проблему выбора транспортного средства для перевозки движимого имущества. Данная статья может оказаться весьма полезной в дальнейших исследованиях.

Ключевые слова: нечеткая логика, нечеткое множество, АТРР, LMAW, cube IQ, Matlab.

Примена Cube Iq софтвера и модела вишекритеријумске оптимизације за избор возила за транспорт робе у Војсци Србије

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ОБЛАСТ: математика, саобраћај, логистика
ВРСТА ЧЛАНКА: оргинални научни рад

Сажетак:

Увод/циљ: Адекватан избор возила који се користи за транспорт робе је веома важан фактор. Он утиче на економичну и рационалну употребу возног парка, као и на квалитет и ефикасност обављања транспортне делатности у Војсци Србије. Пројекат овог модела може да помогне органима саобраћајне службе да, на основу *дефинисаних критеријума, одаберу возило које је најбоље за извршење постављеног транспортног задатка.*

Методе: Предлаже се модел за избор возила за транспорт робе применом fuzzy логичког система, као једне врсте система вештачке интелигенције. За решавање проблема избора возила за транспорт робе дефинисано је пет критеријума, на основу анкетирања командира транспортних водова, који представљају улазне вредности у fuzzy логички систем. Улазне променљиве представљене су са по три функције припадности, док је излазна променљива дефинисана са пет функција припадности. Сва правила у fuzzy логичком систему одређена су применом методе агрегације тежине премиса правила (АТПП), која омогућава формирање базе првила на основу искуства. Применом ове методе, као и на основу броја улазних променљивих и броја њихових функција припадности, дефинисана је база од 243 правила. Вредности тежинских коефицијената функција припадности одређене су применом LMAW методе. За развијени fuzzy логички систем израђен је кориснички „интерфејс” програм који омогућава практичну примену овог модела.

Резултати: Модел је тестиран на примеру избора оптималног возила за робу која је транспортована на ИВП „Пасуљанске ливаде” 2020. године. Избор оптималног транспортног средстава вршен је између транспортних моторних возила која се највише користе у Војсци Србије, а то су: ТАМ 150 Т11, ФАП 2026 И ФАП 1118. Након паковања сва три возила овом робом у Cube IQ и извршеном прорачуну и евалуацији појединачног возила у корисничком „интерфејс” програму добијене су вредности излазне променљиве за свако возило. Те вредности за свако возило су рангиране, па се показало да је оптимално возило за транспорт дефинисане робе ФАП 1118.

Закључак: Овај рад један је од првих који доказује примену модела заснованог на вештачкој интелигенцији који решава проблем избора возила за транспорт покретних средстава. Такође, рад пружа велике могућности за даља истраживања.

Кључне речи: fuzzy логика, fuzzy скуп, АТПП, LMAW, Cube IQ, Matlab.

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