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DESIGN LOGICAL LINGUISTIC MODELS TO CALCULATE NECESSITY IN TRUCKS DURING AGRICULTURAL CARGOES LOGISTICS USING FUZZY LOGIC

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Abstract: The study is aimed to develop the logic-linguistic models to design a number of rules for the correct calculation of the vehicles needed, taking into account the technical, technological, and weather and climate conditions of the harvesting and transport complex. The article has shown that the construction of the design of logic-linguistic models was not performed earlier to solve the problem of the agro-industrial production transportation support, considering the opportunity of forecasting size of influences of the weather and climatic factors on improving the productivity of the harvesting and transport complex elements. It is determined that the experience of applying the fuzzy logic theory in many practice situations confirms the universality of the mathematical apparatus. This toolkit provides better results than classical approaches (set theory, probability theory). This aspect indicates the expediency of the chosen mathematical apparatus for solving the tasks. The article using fuzzy logic explores the relationship and interdependence of technical, technological factors and weather and climate conditions for modeling transport support in harvesting and transport complex. Fuzzification of the parameters is carried out, based on the compiled equations using trapezoidal and triangular membership functions. The set of rules necessary for the creation of logical-linguistic models (LLM) for each factor has been arranged. LLMs were developed for dependent parameters, which will allow further modeling of the transport support of the harvesting and transport complex in the Fuzzy Logic Toolbox application of the MATLAB package.

1 Introduction

Transport support in agriculture, as in other industries, plays a key role. The consumer price of products largely depends on the efficiency planing of the transportation process. This is because the share of the cost of transportation is 20-30% of the final cost [1,2]. This trend is especially clearly seen in the delivery of agricultural goods during harvesting.

This period is characterized by the intensification of the use of rolling stock and harvesting equipment (combines, tractors, etc.). Therefore, the complexity of the organization of transport services at a sufficient quality level increases. In this case, the main factor for improving the reliability of the logistics system is the accuracy of determining the required number of trucks for the transportation of agricultural goods.

Based on the practice of functioning and interaction of the harvesting and transport complex (HTC) elements during the harvest, there is a problem of ensuring uninterrupted operation between harvesting equipment and vehicles. There is an option to solve this problem by applying standard technological solutions [3,4]. It is possible to take into account technological aspects using probabilistic approaches [5-8], as well as risk theory [9]. However, in order to properly plan the operation of the harvesting and transport complex, it is necessary to predict the harvesting time and possible timing. To do this, the model should include parameters that take into account weather and climatic conditions.

Therefore, the use of fuzzy logic to build logical-linguistic models is the most correct. Indeed, the application of this approach allows fully reducing the fuzziness in the system under consideration, which will allow us to determine the required number of trucks with a smaller error for various scenarios than with the use of probability theory [10].

The study aims to develop the logical and linguistic models that allow creating a set of rules for the correct calculation of the necessity of the vehicle, taking into account the technical, technological, and weather and climatic conditions of the harvesting and transporting complex.

2 Literature Review

The experience of using fuzzy logic in logistics and transport systems proves the appropriateness of using this mathematical apparatus when it is necessary to consider fuzzy parameters during model building.

One of the first problems that were successfully solved using the fuzzy logic apparatus were tasks in the medical field. Today, this issue is also significantly reflected in modern research, additionally using neural-network models [11]. Similar approaches are used in logistics and to improve the functioning of various types of transport systems.

Fuzzy logic has been successfully applied to increase the safety of vehicles on the road network sections in the settlements [12] at the beginning of the 21st century. Several works were carried out in the area of smart transport systems, where the issues of timely determination of congestion [13,14] and general problems of managing saturated traffic flows were solved, using the hierarchy method to assess the different levels of control [15,16]. Another practical area of application of fuzzy logic, according to the results of research in the sphere of road transport, is designing an evolutionary-type model for the prediction of possible traffic accidents in city networks [17].

The next study was based on an approach that would maximize profits when planning the transportation of solid materials using pipelines. The solution to the problem was made possible by creating a new design of fuzzy logic systems (IT2FLS) type interval 2 [18].

Separately, it is worth noting the use of the fuzzy logic apparatus in solving the multiobjective nonlinear transportation problem (MNOTP), where the weighting coefficients of the membership functions are presented particularly [19]. Fuzzy logic is also used in large-scale research, for example, in determining the overall level of security of transport infrastructure. It can be done only by fixing the uncertainty of environmental threats the transport infrastructure faces, as well as its resistance to damage and the consequences of damage [20]. Such approaches are often used in the absence of the possibility of obtaining the necessary statistics or complete lack of data.

Often the fuzzy models are used to organize traffic routes of various modes of transport: automobile [21,22], rail transportation [23], and ship navigation [24]. Routing aspects are important enough to determine the best option for transport support of any industry [25]. An innovative solution to this problem was the use of a modified ant algorithm [26]. It should be noted that when building a supply chain that includes a distribution center, a fuzzy theory application is also possible [27].

As for the issues of transport support for the agricultural sector, these tasks were considered using the fuzzy logic apparatus of the fleet of vehicles, primarily involved in harvesting [28]. A similar study was conducted to optimize the work of the farm in growing tomatoes [29]. The fundamental research in terms of the transport process planning in agriculture was a study designed to solve the main transportation problems by adjusting the membership functions to the specifics of the system under study. In this case, only three factors were considered that were associated only with the technical aspects of transportation [30].

When planning the delivery of agricultural products, the key role is played by the issues of coordinated work of harvesting and transport equipment. At the same time, ensuring coordinated interaction can be achieved using the theory of fuzzy sets and neural networks to obtain accurate forecasts in difficult to predict operating conditions. From this point of view, studies were conducted for determining the transshipment volumes of grain in logistics systems [31-32], as well as the calculation of demand in ports of departure depending on soybean production [33]. Moreover, according to studies, in general, supply chain management should be based on the use of models with the necessary data coverage [34]. A similar sample is shown when constructing supply chain options for the delivery of grain cargo by three transport modes [35]. However, a classical approach is presented here, using the Petri nets apparatus, which does not always allow finding an unambiguous optimum.

Regardless of the specifics of the fuzzy logic apparatus application, the key aspect was the correctness of the formulation of many terms and, as a result, the correctness of constructing a logical-linguistic model (LLM). In the paper [36] an example of the logical-linguistic models' development with the programming languages using the classical Zadeh theory is shown.

It should be noted that LLMs are used along with mathematical ones and are the most productive for the efficient presentation of data. Based on logical-linguistic models, it is possible to implement the creation of an intelligent interface of computer programs and the operating system as a whole [37].

The logical-linguistic models are the most acceptable type of models used in intelligent systems for processing complex structures of diverse types of data and knowledge. A typical example of the LLM is the concept that reflects the laws inherent in classes of objects [38].

The information sources and scientific literature analysis showed that the construction of the logical and linguistic model was not carried out earlier for the transport support of agricultural production, considering the results of forecasting values of the weather and climate factors influence on improving the efficiency of the HTC elements functioning.

The diversity of the fuzzy logic theory application testifies to the universality of the mathematical apparatus, which, when solving various problems, shows better results than classical approaches. Therefore, this is another proof of the relevance of the selected tools for solving the given tasks.

3 Research Methodology

3.1 Research tasks

To achieve the goal, a research structure has been developed, according to which must be resolved the next problems:

1. Segregation of the future model parameters into dependent and independent according to the formed logical chains;
2. Definition of the influential dependent parameters and those affected by the system elements;
3. Formation of the logical chains that show the interconnection and interdependence of the parameters when modeling the transportation support for the HTC;
4. Assignment of terms for each term-set of linguistic variables;
5. Fuzzification for each system parameter;
6. Development of logical-linguistic models. Adjustment of the set of rules for each model.

The final step is the result of this study. At the same time, the constructed logical-linguistic models with the formed individual set of rules will act as initial information at the next stage of the study - computer simulations using the Fuzzy Logic Toolbox profile package in the MATLAB simulation shell.

3.2 Parameters classification

The classification of parameters was performed in order to develop a matrix for constructing logical chains. At the same time, an object-independent approach is practiced. It involves a third-party assessment of the objects presented for classification. They should be assessed objectively, which is possible with the involvement of independent experts [39-41]. As a result, dependent and independent parameters are highlighted. Independent parameters are marked with “-” and dependent parameters are marked with “+”. The results are presented in Table 1.

Table 1 Classification of dependent and independent parameters

Dependent parameter “+”	Independent factors “-”
Soil condition	Rain
	Dew
Crop productivity	Hail
Crop moisture	Field size
Lodging	Soil moisture content
Quantity of harvesters	Harvester header width
Harvester speed	Road type
Harvester efficiency	Load capacity of vehicles (trucks)
Quantity of vehicles (trucks)	Distance from field to the threshing-floor
Vehicles (trucks) operating speed	
Vehicles (trucks) turnover time	
Method of harvesting	

The presented classification fully reflects the objective opinion of various expert groups on the degree of influence or independence of each parameter from the set of proposed factors. Table 1 allows establishing the influence levels of both dependent factors and independent ones. This will allow us to more correctly formulate the future logical-linguistic model, which in the conditions of fuzziness makes it possible to reduce the error in obtaining the final result – the number of vehicles involved in the transport support.

3.3 Definition of influence levels of independent to dependent parameters

The classification of the basic conditions for the HTC operation and consideration of the experts' recommendations made it possible to identify the levels of the interdependence of parameters. Thanks to this aspect, it is possible to determine the dependence of the studied factors. It should be noted that the dependence of the parameters will occur both in the context of "dependent parameters – independent parameters", and in the logical chain "dependent parameters – dependent parameters". Dependent parameters are listed, and their dependence on independent parameters is indicated (Table 2):

Table 2 Influence levels of independent to dependent parameters

Independent factors which influence	Influenced dependent parameters
Rain	Soil condition
	Crop moisture
	Lodging
	Vehicles (trucks) operating speed
Dew	Crop moisture
Hail	Lodging
Field size	Quantity of trucks
Soil moisture content	Soil condition
Combine header width	Combine efficiency
Road type	Vehicles (trucks) operating speed
Load capacity of vehicles (trucks)	Vehicles (trucks) turnover time
Distance from field to the threshing-floor	Vehicles (trucks) turnover time

Based on Table 2, we can conclude that the most significant (from the point of view of the number of influence levels) is the independent parameter "Rain". This factor affects four elements of the system under study. Therefore, when constructing logical chains, "Rain" should be reflected in the largest number of them.

Similarly, the study performed the formation of levels of interconnections in the logical chain "dependent parameters – dependent parameters". The results of the procedure were reflected in the development of the final logical chains presented in the matrix (Table 3).

3.4 Formation of logical chains

When developing future logical-linguistic models, it is important to pay attention to the primary technological, technical, and weather-climatic aspects in which the transport support of the harvesting and transport complex takes place [42,43]. For this, matrix-forming logical chains were created (Table 3).

Based on Table 1, three alternatives for constructing logical chains are identified, which are built on, apart from the technical and technological aspects of the HTC operation, weather, and climatic factors. The latter primarily affect the start time of the harvesting and its duration, which ultimately determines the quantitative need for rolling stock. Moreover, the largest number of construction chains are based on the weather conditions of the harvesting and transport complex. This will naturally affect the construction of logical-linguistic models in subsequent stages.

3.5 Definition of fuzzy term-sets and finding values of linguistic variables

The preparatory stage should be carried out in order to complete the fuzzification (the transition from a clear set to a fuzzy one) [44]. It consists of the development of term sets for each model and, accordingly, the definition of the values of linguistic variables for a particular term. The results of the procedure are presented in Table 4 for independent factors.

The results of parametric identification are performed for dependent factors in Table 5.

Table 3 Matrix of logical chains for design linguistic models

Kind of factor	Initial parameter	Transit chain	Result
Weather conditions	Rain	Lodging-method of harvesting-harvester speed-harvester efficiency-quantity of harvesters	Quantity of trucks
		Soil condition- harvester speed-harvester efficiency-quantity of harvesters	
		Lodging- crop productivity-quantity of harvesters	
		Vehicles (trucks) operating speed-vehicles (trucks) turnover time- quantity of harvesters	
	Hail	Lodging-method of harvesting-harvester speed-harvester efficiency-quantity of harvesters	Quantity of trucks
		Lodging- crop productivity-quantity of harvesters	
	Dew	Crop moisture-method of harvesting-harvester speed-harvester efficiency-quantity of harvesters	Quantity of trucks
		Crop moisture- crop productivity-quantity of harvesters	
Technical aspects	Soil moisture content	Soil condition-harvester speed-harvester efficiency-quantity of harvesters	Quantity of trucks
	Harvester header width	Harvester efficiency-quantity of harvesters	Quantity of trucks
	Load capacity of vehicles (trucks)	Vehicles (trucks) turnover time-quantity of harvesters	Quantity of trucks
Technological aspects	Road type	Vehicles (trucks) operating speed-vehicles (trucks) turnover time-quantity of harvesters	Quantity of trucks
	Distance from field to the threshing-floor	Vehicles (trucks) turnover time-quantity of harvesters	Quantity of trucks
	Field size	Quantity of combine harvesters	Quantity of trucks

It should be noted that to highlight the values of linguistic variables, both expert recommendations and mathematical expediency were used at the same time. The latter refers to the minimum possible allocation of the number of ranges (terms) by the factor to prevent the massiveness of the final model. Indeed, this can reduce the speed of calculations or lead to the inability to experiment as a whole.

3.6 Parameter system fuzzification and designing of membership functions

The next step is the process of fuzzification of system parameters. Thanks to this procedure, it is possible to convert fuzzy parameter values to linguistic truth-values [45].

A comparative assessment between membership functions has shown that triangular and trapezoid membership functions will best represent dependencies. A similar type of function is often used in solving logistic problems. Confirmation of this is one of the latest studies performed when choosing a route in the formation of the supply chain in fisheries [46].

Fuzzification was performed for all dependent and independent parameters using the classical approaches of the theory of fuzzy logic,. As an example, this article discusses a procedure based on the logical link “Dew” (independent factor) “Crop moisture” (dependent factor). The choice of this pair is because the independent factor (“Dew”) is harder to predict than the three aspects of the considered weather and climate conditions. In this case, the dependent parameter (“Crop moisture”) plays a key role in choosing the start time of the harvest and the total duration of the harvesting and transport complex, at which the harvested crop will be of the best quality.

Triangular and trapezoidal membership functions are the simplest, according to the research study [47]. These functions are formed using the piecemeal-linear approximation. The trapezoidal membership function is a generalization of triangular function. It allows you to specify the core of a fuzzy set in interval form. Following convenient interpretation is possible in case of trapezoidal membership function: a core of a fuzzy set is an optimistic estimate; fuzzy set carrier – pessimistic evaluation. Triangular and trapezoidal membership functions are most widely used in practical applications according to the work of prof. Rothstein [48]. These two studies explain why such types of membership functions are expediently for using during the experiment.

Fuzzification for the parameter “Dew” will take the following form (Figure 1).

Table 4 Terms and values of linguistic variables for independent parameters

Parameters / conditions	Term	Index
Rain	Lingering	10-20 mm
	Heavy	10 mm
	Short term	5 mm
Dew	Long	7 hr
	Moderate	5 hr
	Short-term	2 hr
Hail	Heavy	10 mm
	Moderate	5 mm
	Small	2-3 mm
Field size	Large	500 ha
	Medium	200-300 ha
	Small	100 ha
Relative soil wetness	High	61,8 %
	Moderate	50 %
	Low	44 %
Header width	Large	11 m
	Medium	7-10 m
	Small	3-6 m
Road type	With improved coating	51-60 km/h
	Grader	35-50 km/h
	Steppe	18-35 km/h
	Field	12-18 km/h
Load capacity	High	20 t
	Higher than average	10-12 t
	Average	5-7 t
	Low	3 t
Distance from field to threshing floor	Long	40 km and more
	Higher than average	20-35 km
	Medium	10-19 km
	Short	2-9 km

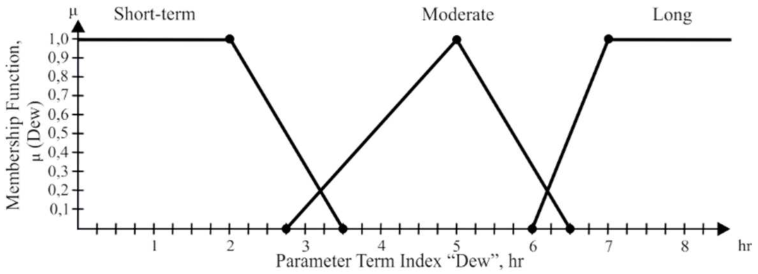

Figure 1 Graphic of fuzzification result for independent parameter 'Dew'

A calculation was also performed for trapezoidal and triangular) membership functions $\mu(u)$ for the parameter “Dew”.

Table 5 Terms and values of linguistic variables for dependent parameters

Parameters / conditions	Term	Index
Soil Condition	Satisfactory	Dry
	Unsatisfactory	Wet
Crop productivity	The highest	50 c/ha and more
	Medium	37,5 c/ha
	Lowest	25 c/ha and less
Crop Moisture	High	25 % and more
	Medium	18 %
	Normal	16 %
Lodging	High	<25 %
	Medium	<15 %
	Low	5 %
Number of Combine Harvesters	High	5 units and more
	Medium	3-4 units
	Low	2 units
Combine Harvester Speed	High	10 km/h
	Normal	5-7 km/h
	Low	2-3 km/h
Combine efficiency	High	5,5 ha/h
	Medium	4,5 ha/h
	Low	3 ha/h
Number of transport means	Above normal	6 units and more
	Normal	3-5 units
	Insufficient	2 units
Vehicles (Automobile) Operational Speed	High	51-60 km/h
	Higher than average	35-50 km/h
	Average	18-35 km/h
	Low	12-18 km/h
Vehicles (Automobile) Time of Turnover	Fast	10-20 min
	Satisfactorily	21-40 min
	Slow	41-60 min
Harvesting Method	Direct	1
	Separate	0

$$\mu(u)=\begin{cases}0, & u\le 0 \ \text{ if } u\ge 3{,}5\\ 1, & 0\le u\le 2\\ \dfrac{3{,}5-u}{3{,}5-2}=\dfrac{3{,}5-u}{1{,}5}, & 2\le u\le 3{,}5\end{cases}, \qquad (1)$$

$$\mu(u)=\begin{cases}0, & u\le 2{,}75 \ \text{ if } u\ge 6{,}5\\ \dfrac{u-2{,}75}{5-2{,}75}=\dfrac{u-2{,}75}{3}, & 2{,}75\le u\le 5\\ \dfrac{6{,}5-u}{6{,}5-5}=\dfrac{6{,}5-u}{1{,}5}, & 5\le u\le 6{,}5\end{cases} \qquad (2)$$

$$\mu(u)=\begin{cases}1, & 7\le u\le 8{,}5\\ \dfrac{u-6}{7-6}=\dfrac{u-6}{1}, & 6\le u\le 7\end{cases}\qquad (3)$$

where u – considered fuzzy parameter; $\mu(u)$ – membership function.

Fuzzification for the “Crop moisture” parameter is shown in Figure 2.

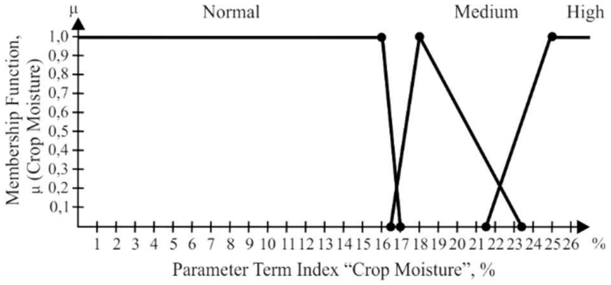

Figure 2 Graphic of fuzzification result for independent parameter “Crop moisture”

Similarly to the “Dew” factor, the membership functions were calculated $\mu(u)$ for “Crop moisture”.

$$\mu(u)=\begin{cases}0, & u\le 0 \text{ if } u\ge 17\\ 1, & 0\le u\le 16\\ \dfrac{17-u}{17-16}=\dfrac{17-u}{1}, & 16\le u\le 17\end{cases}\qquad (4)$$

$$\mu(u)=\begin{cases}0, & u\le 16{,}5 \text{ if } u\ge 23{,}25\\ \dfrac{u-16{,}5}{18-16{,}5}=\dfrac{u-16{,}5}{1{,}5}, & 16{,}5\le u\le 18\\ \dfrac{23{,}25-u}{23{,}25-18}=\dfrac{23{,}25-u}{5{,}25}, & 18\le u\le 23{,}25\end{cases}\qquad (5)$$

$$\mu(u)=\begin{cases}1, & 25\le u\le 27\\ \dfrac{u-21{,}5}{25-21{,}5}=\dfrac{u-21{,}5}{3{,}5}, & 21{,}5\le u\le 25\end{cases}\qquad (6)$$

The presented example allows building a logical-linguistic model of the dependent variable “Crop moisture”. The fuzzification procedure was carried out similarly for the other factors of the functioning of transport services during the harvesting period described in Section 3.1.

4 Results and Discussion

Eleven logical-linguistic models were built as a result of the study. At the same time, for example, the fuzzy mathematical model of “Crop moisture” in the form of a linguistic model consists of 9 rules and will take the following form:

$$\begin{cases}
IF\text{ "Rain } \textit{Short term}\text{"}\rightarrow THEN\text{ "Crop moisture } \textit{Normal}\text{"}\\
IF\text{ "Rain } \textit{Heavy}\text{"}\rightarrow THEN\text{ "Crop moisture } \textit{Medium}\text{"}\\
IF\text{ "Rain } \textit{Lingering}\text{"}\rightarrow THEN\text{ "Crop moisture } \textit{High}\text{"}\\
IF\text{ "Dew } \textit{Short term}\text{"}\rightarrow THEN\text{ "Crop moisture } \textit{Normal}\text{"}\\
IF\text{ "Dew } \textit{Moderate}\text{"}\rightarrow THEN\text{ "Crop moisture } \textit{Medium}\text{"}\\
IF\text{ "Dew } \textit{Long}\text{"}\rightarrow THEN\text{ "Crop moisture } \textit{High}\text{"}\\
IF\text{ "Dew } \textit{Short term}\text{"}\rightarrow AND\text{ "Rain } \textit{Short term}\text{"}\rightarrow THEN\text{ "Crop moisture } \textit{Normal}\text{"}\\
IF\text{ "Dew } \textit{Moderate}\text{"}\rightarrow AND\text{ "Rain } \textit{Heavy}\text{"}\rightarrow THEN\text{ "Crop moisture } \textit{Medium}\text{"}\\
IF\text{ "Dew } \textit{Long}\text{"}\rightarrow AND\text{ "Rain } \textit{Lingering}\text{"}\rightarrow THEN\text{ "Crop moisture } \textit{High}\text{"}
\end{cases}\qquad (7)$$

The final table with a set of rules for each of the 11 developed logical-linguistic models can be represented as follows (Table 6).

Table 6 Resulting table with rules quantities for each logical linguistic model

Fuzzy logical linguistic model	Rules quantity
Soil condition	9
Crop productivity	3
Crop moisture	9
Lodging	9
Quantity of harvesters	15
Harvester speed	4
Harvester efficiency	11
Quantity of vehicles (trucks)	6
Vehicles (trucks) operating speed	6
Method of harvesting	11
Vehicles (trucks) turnover time	15

Table 6 shows that the most cumbersome is LLM, which determines the technology of the transportation process and the harvesting equipment operation. These models consist of 15 rules, which makes it necessary to take into account more conditions when calculating the number of harvesting combines needed, as well as planning the turnover time for trucks involved directly in the transportation of the HTC. Therefore, in order to avoid the disruptions in possible operation, these two indicators should be agreed upon to exclude both the downtime of the combine waiting for the truck and, conversely, the formation of a queue of empty trucks near the field.

5 Conclusion

The paper studies the interconnections and interdependencies of the technical, technological factors and weather and climate conditions for further modeling of the transport support for the harvesting and transport complex. A classification is made with finding mutual influence between the variables of the system under study. Based on this, the matrix of logical chains between the parameters (weather, climate, technical, and technological) is developed.

The process of assigning terms to each of the dependent and independent parameters was carried out, and the values of linguistic variables were assigned. Parameters were fuzzified based on the equations made using trapezoidal and triangular membership functions. The set of rules necessary for creating logical-linguistic models (LLM) for each factor has been compiled.

The logical-linguistic models have been developed to solve the problem of transport support for agro-industrial production, considering the opportunity to forecast values of the weather and climatic factors that influence the efficiency increase of the harvesting and transport complex elements functioning.

The developed LLM for dependent parameters will allow further modeling of the transport support of the harvesting and transport complex in the Fuzzy Logic Toolbox application in the MATLAB package. According to the results, you can get a set of rules for all the elements of the fuzzy system, in which the required number of trucks is more accurately calculated under various, even the most implicit, conditions of operation of the HTC.

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