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The Mathematical Modeling Stages of Combining the Carriage of Goods for Indefinite, Fuzzy and Stochastic Parameters

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Abstract: Combined cargo transportation in Ukraine is characterized by the presence of uncertain risks. The aim of the article was to propose a mathematical model for choosing the mode of transportation that would correspond to the best value of the integral objective function in the presence of fuzzy, stochastic and uncertain risk parameters. The efficiency of the mathematical model provided the possibility of forming not only long-term forecasts that require significant time, but also short-term forecasts in real time. This allows to quickly change routes and conditions of transportation. Practical testing of the mathematical model revealed the assimilating nature of some uncertain risks. The results of the analysis are given in the article. The realization of such a risk leads to a radical change in all conditions of transportation. Long-term forecasts allow to predict new routes and conditions of transportation.

Keywords: Mixed transportation, mathematical model, uncertainty, fuzzy and stochastic parameters.

1. Introduction

In the presence of fuzzy factors and parameters, characterized by a large degree of uncertainty, combined transportation (CT) management is so complicated that the use of mathematical modeling methods is often limited to the processing of expert assessments. This leads to a high level of subjectivity of estimates, a decrease in their relevance and, consequently, an increase in the cost of transportation. The cost of transportation under these conditions will be higher, since the operators of the CT will take into account the impact of uncompensated risks in the cost of services.

The uncertainty in combined transport in Ukraine is due to many factors. These factors, in our view, include, in particular, the possibility of broad-scale aggression; high volatility of the national currency; a significant degree of undervaluation of the national currency, which can lead to a significant surge in exchange rate caused by panic in the foreign exchange market, etc.

Different approaches were used to predict the behavior of the system under the uncertainty factor. In particular, mathematical simulation of the system was performed on the state and numerical value of the output parameter of which the disturbing signal operates. This mathematical model was studied in the works of P. Tomey, R. Ortega and others [1]. It is for such systems that adaptive methods have begun to be used.

To evaluate the impact of uncertain and fuzzy parameters, the possibility of modeling systems using nonlinear generators was investigated. Control of systems in the presence of chaotic external influences was researched in the works of M. Zapateiro, Y. Vidal, L. Acho [1]. Control of the system by the method of compensation for nonlinear external

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influences, with the condition of the generalization of the system model was researched in the works of L. Marconi, L. Praly, R. Marino, G.L. Santosuosso, P. Tomei, and others [2], [3], [4]. [5], [6]. These scientific works have been analyzed and the complexity or inappropriateness of their use for estimating and taking into account the uncertainty factors in the modeling of CT has been determined. But some mathematical approaches to solving the problems in the mentioned works were used in the developed algorithms. Different approaches are used for mathematical modeling of transport systems, including the use of graph theory [7], [8], [9], [10], [11]. In our view, the approach to mathematical modeling of combined (multimodal) transportations described in the work [12] is more appropriate.

In our opinion, the task of managing the CT should be considered as the choice of the best path for the selected target function from the starting point to the point of destination with replacement of certain stages if they do not correspond to the target function, in real time. The choice of path steps, by definition of CT, which are guaranteed to be available at the time of the problem, is performed in accordance with the optimization of the selected integral target transport function. The choice of the best path option from the options both at the starting point and at each stage is connected with a great deal of uncertainty.

Problems that arise when solving this problem:

1. The incomparability of the mathematical methods used in each of the stages.
2. The presence of uncertainty in the a priori choice of adaptation method in the CT process.
3. Uncertainty related to the non-monotonicity of the effectiveness function during cargo transportation.
4. Instability of algorithms. Which is related to the uncertainty of the parameters of the integral target function.
5. Construction of a universal mathematical model for all variants of stages of transportation and sets of parameters of the target function with the choice of the most efficient algorithm, which depends on the factors of uncertainty for each stage of the CT.

The purpose of this article was to propose a mathematical model for selecting the transportation path that would correspond to the best value of the integral target function with the possibility of adjusting the path at each of the stages of transportation in accordance not only with fuzzy and stochastic parameters but also with uncertainty factors.

2. Methodology

In the work [12], the problem of multimodal (combined) transportation of cargoes is proposed to be considered by means of the construction of an appropriate digraph. The factor of uncertainty and fuzzy variables complicates the implementation of the method described in [12].

To solve this problem, we propose to use the method of finding the best path that corresponds to the integral destination function of transportation, in a fuzzy orthography, in an adaptive manner, using soft calculations, minimal dominant half-variants of sets of nodes or edges of a graph. By definition, a semi-variant, unlike an invariant, can be modified in some way.

Uncertainty leads to the need to generalize the method described in [12], using the recommendations given in [14], [15] applying intuitionistic dominant half-variants (IDNs), unlike fuzzy sets, IDNs are characterized to some extent by independence of degrees of membership and non-membership.

That is, the IDN defined on the continuum $\boldsymbol{W}$ can be represented as:

$$Q = \{\langle w, \mu_Q(w), \vartheta_Q(w)\rangle | w \in W\} \quad (1)$$

where $\mu_Q(w) \in [0,1]$ та $\vartheta_Q(w) \in [0,1]$ - accordingly are the degree of membership and non-membership of $\boldsymbol{w}$ to $\boldsymbol{Q}$ provided

$$(\forall w \in Q)[(\mu Q + \vartheta Q) \leq 1] \quad (2)$$

Then the digraph for the intuitionistic fuzzy set (IFS) when the edges and nodes belong to the intuitionistic set can be represented as $\tilde{P}$ =$(Q,\boldsymbol{H})$ where $Q = \langle B, \mu_Q, \vartheta_Q\rangle$ B - the corresponding IFS is defined at the set of nodes **B,** $\boldsymbol{H}= \langle B \times B, \mu_H, \vartheta_H\rangle$ IFS for which

$$\mu_H(wl) \leq min\left(\mu_Q(w), \mu_Q(l)\right) \quad (3)$$

$$\vartheta_H(wl) \leq max\left(\vartheta_Q(w), \vartheta_Q(l)\right) \quad (4)$$

subject to the condition

$$(\forall w, l \in B)[0 \leq (\mu_H(wl) + \vartheta_H(wl)) \leq 1] \quad (5)$$

If we denote the degree of dominance by $\alpha(W)$**,** , then the dominant IFS W_α which, from the point of view of control theory, will represent the so-called "trunk set" belonging to the continuum $\boldsymbol{W}$ for the digraph $\tilde{P}$ and will determine the so-called "trunk graph". This trunk graph can be used to find the route that corresponds to the optimum or, if necessary, the suboptimal of the integral target function. As a suboptimal of the integral target function, we determine the best value of this function for the variants of the route on the digraph $\tilde{P}$ by realizing threats that were previously defined as uncertainties for a given route.

A bounded set of nodes and edges is called a "trunk" when it belongs to the so-called "navigational" set of nodes and edges of a continuum $\boldsymbol{W}$ for a digraph $\tilde{P}$ by which a variant of a route from the initial to the final node of this route can be realized. That is, a graph that has a specified limited set of nodes and arcs (the so-called trunk graph) belongs to the so-called "navigation" graph.

3. Algorithm, results and discussion

The proposed mathematical model can be attributed to the type of pseudo-dynamic "rough" (or so-called "hard") models. Its classification as pseudo-dynamic is explained by the fact that the use of digraph limits the direct dependence of the system on time. The implicit dependence on time, in this case, is manifested only in a sequential set of static states of the model corresponding to the flow of real time. The classification of the proposed model as "not rough" is explained by the fact that it estimates the limits of instability of the system, when small changes in parameters lead to a change in the so-called number of degrees of freedom.

This allows for an algorithm (See Fig. 1) that uses a large amount of computer resources and will take longer to calculate, but will provide a more relevant result and, to a greater extent, meet the needs of practitioners. This is due to the fact that the membership of a set of nodes and edges to the IFS leads to the use of fuzzy sets of much higher order.

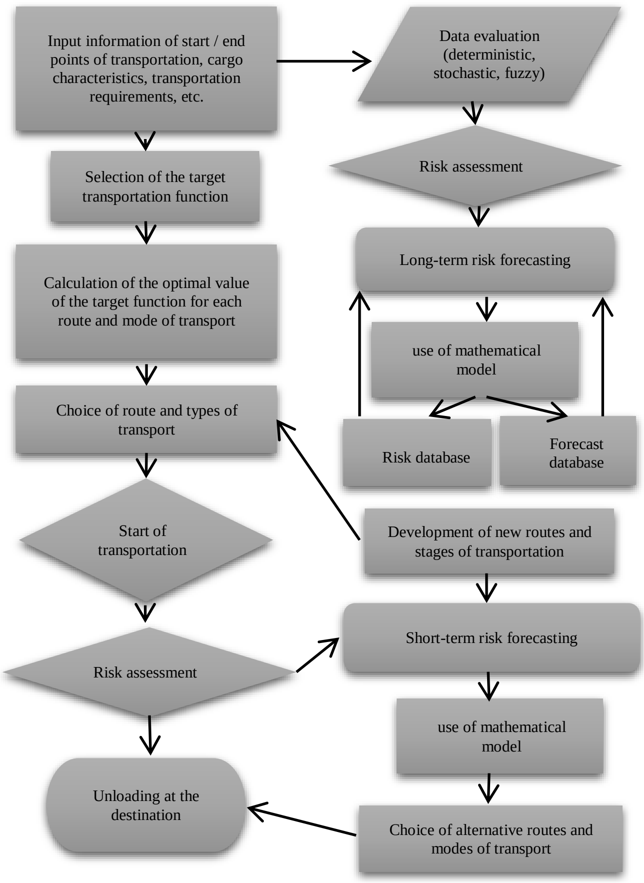

Fig. 1 - Flowchart of algorithm implements a universal mathematical model

Then the algorithm of using IFS will have the following steps:

- formation of IFS as a collection of all nodes and edges that can be assigned to the navigation set;
- charting of the navigation graph based on the existing navigation sets;
- search for subsets in this graph that can be defined as the minimal dominant ones;
- charting of a trunk graph, which includes the found minimal dominant subsets;
- transformation by way of adaptive soft calculations of indeterminate variables to fuzzy or stochastic ones;
- transition to the use of mathematical apparatus of regression-correlation analysis and fuzzy logic.

As shown in Fig. 1. The mathematical model is a necessary, effective, important part of the overall algorithm, but only a part of it. The result of using the model is creating a short-term or long-term forecast, using which logistics operators, owners of transport companies will decide on the feasibility of using any route of the MT or its particular sector, or any mode of transport within the changes in risk parameters. Using the mathematical model for a rapid change of the route will be possible only if the time required for forecasting is minimized.

The use of the apparatus of correlation-regression analysis in the case of multimetric regression (and the factors of CT, characterized by the presence of uncertainty, as the study showed, are multimetric) is complicated by the multicollinearity of the parameters. For cases where the mathematical apparatus of regression-correlation analysis cannot be used, it is suggested to use the mathematical apparatus of fuzzy sets, if necessary, combining them according to the algorithm [12].

Multicollinearity, by definition, is described by linear functions of interdependent parameters. As the evident functional relationship of the parameters for the CT is practically eliminated, it is worth focusing on the latent stochastic dependence of these parameters. To determine the communication density, we will apply an algorithm developed to perform this task. This algorithm is executed in the following sequence. The matrix of correlation coefficients of parameters is evaluated in pairs. The corresponding multimetric correlation and determination coefficients are defined. Given a certain level of significance of these coefficients, the formation of the regression equation is performed The check of the functional dependency of the specified parameters is envisaged. If confirmed, this indicates complete multicollinearity. Then the parameter matrix will be degenerate, which by definition means the absence of the inverse matrix. Namely, the inverse matrix is required for the least squares estimation. That is, under this condition, we cannot find the regression equation. In this case, we use soft calculations. But complete multicollinearity is unlikely. Partial multicollinearity leads to an increase in the variance of factor variables, which leads to a decrease in the accuracy of interval estimates, the formation of incorrect estimates of the significance of the parameters, the inability to determine the individual influence of the parameter on the relevant factor, the instability of estimates using the least squares method.

An indicator of the presence of multicollinearity is the approximation of the determinant of the correlation matrix to zero. The approximation of the determinant of the correlation matrix to one will indicate the absence of multicollinearity. To reduce multicollinearity, we use adaptive algorithms to sequentially exclude parameters or transform variables by applying not directly the parameters, but the differences of their values at the beginning and end of each stage of transportation. The next step in the algorithm is to check the reduction degree of the determination coefficient. This, in turn, allows us to estimate the trends of increasing or decreasing the relevance of the mathematical model.

As a result, for the multicollinear factor θ, which depends on the parameters z_j an analog of the known equation is used

$$\vec{\theta} = a + \vec{b} * \vec{z} \quad (6)$$

where θ is the vector of risks, $\vec{b}$ is the vector of regression equation coefficients, $\vec{z}$ is the vector of parameters.

Or, if necessary, the above form of equation (1) is used to determine the resultant feature.

If it is necessary to determine the change of parameters in time, the following dependencies are used

$$dz/d\tau = \gamma(\vec{z}, \vec{v}) + f(\vec{z}, \vec{v})\vec{\mu} \quad (7)$$

$$g = \delta(\vec{z}, \vec{v}) \quad (8)$$

$$\vec{v} = M(u, \vec{v}) \quad (9)$$

where $\vec{z}(\tau) \in R^n$ is a vector that determines the state of the n-dimensional system at time τ; $\vec{\mu}(\tau) \in R^k$ is a vector that defines a set of $\boldsymbol{k}$ control actions at time τ; $\tau \in (\tau_i \dots \tau_{i+1})$, τ_i is the time of the beginning of the *i*-th stage of cargo transportation; τ_{i+1} is the time of the end of the *i*-th stage of cargo transportation; $\vec{g}(\tau) \in R^k$ is a vector that determines the limits of the intervals of admissible parameter changes at timeτ; $\vec{v}(\tau) \in R$ is the vector of the state of external influence on the system; $u \in R$ is the vector of uncertain parameters, δ, γ, f, M are the vector functions of the specified variables.

We have implemented the CT management algorithm in such a way as to ensure coordination of two tasks: efficiency of the solution and minimization of the cost of transportation under the conditions:

$$\tau_i \in [0, \tau], \quad (10)$$

$$C_i \leq C_{max}, w_j \in W, \boldsymbol{i} \in \{0, i_{max}\} \quad (11)$$

where τ_i – is the time of the CT stage, C_i is the cost of the transportation stage.

The algorithm for this part of the problem can be formulated as follows. We divide the continuum $\boldsymbol{W}$ into sub continuums of stochastic parameters and fuzzy variables.

Then for the sub continuum of stochastic parameters:

$$T = \{(\vec{w},\vec{p}) \langle F, ⅏\rangle \beta_F\} \quad (12)$$

where $(\vec{w},\vec{p})$ is the part of the continuum $\boldsymbol{W}$ for which each component of the vector $\vec{w}$ is stochastic. That is, each component of the vector $\vec{w}$ corresponds to a component of the probability vector $\vec{p}$, which can be described by an algebraic system with an integral target function F, that has all the properties of the so-called "compositions" ⅏, including seclusion, associativity and, all other things being equal, cargo transportation, idempotency.

Then the conditions of equation (7) can be represented as

$$\tau = \sum_0^i \tau_i \quad (13)$$
$$\mathbf{C}=C_1 * C_2 * \ldots * C_i \sum(+/-\Delta_k) \to min \quad (14)$$

where the sign $*$ denotes the effect of adding on the additive cost function, or the multiplication action on its multiplicity, Δ means the total possible profits (such as bonuses) or losses (eg penalties).

For the sub continuum of fuzzy variables to which ***FN***-number arithmetic (Fuzzy Naturale) is applied, we can write:

$$T = \{(\vec{w}/\vec{N}) \langle F, ⅏\rangle \beta_F\} \quad (15)$$

where $\vec{N}$ is the vector of relations.

The uncertainty of the parameter is reduced to the inaccuracy of the use of soft calculations in the modeling of a particular stage of transportation, characterized by the specified parameter according to the method described in [15]. This is done by replacing the indeterminate parameter (tensor) with its invariants using the Kronecker method to form the product "variable - function of membership". That is, summing up, the reduction of an indefinite parameter to a Kronecker product of fuzzy variables.

Using graph theory methods to formulate a route, this will be realised on a digraph by the algorithm of selecting nodes closest to the current one which are connected with the terminal route by intermediate edges and nodes with no signs of uncertainty. Then the problem is reduced to the method described in [12] for finding the optimal path l_{opt} by selecting more efficient nodes (edges, stages of transportation) on the digraph.

$$l_{opt}(w_0 ⅏ \{w_j\}) = min_{C(w_0 ⅏ \{w_j\})} \sum l_j \quad (16)$$

under the condition that:

$$C \to C_{opt}(w_0 ⅏ \{w_j\}) \quad (17)$$

where $l_j, \overrightarrow{w_j}_j$- $j -$ i route stages and parameter vectors defining these stages.

The above algorithm implements a universal mathematical model (see Fig. 1), which is suitable not only for management tasks but also for predicting the CT.

With the use of this model, the gross volume of combined transportations of Ukraine by individual types of cargo for the years of 2020 and 2021 was carried out with uncertain parameters.

The result of forecasting using the work data [16, 17] is shown in Fig. 2, Fig. 3, Fig. 4.

The prediction is made in optimistic and pessimistic versions. The optimistic variant is calculated based on the set of existing risks commonly found in CT, by changing the parameters of the statistical and fuzzy parameters of their impact within the limits of the forecast estimates. The pessimistic variant is calculated by implementing the two worst case scenarios of undetermined risks: intensification of military actions and domino effect in the national currency exchange rate. For the variant of the fall in the national currency exchange rate, we used the scenario of 2016, when within a few weeks there was an almost 2.3 times fall in the national currency exchange rate. The optimistic forecast in the figures is indicated by a solid line, pessimistic (military actions) is shown by a dotted line, pessimistic (change in the national currency exchange rate) is shown by a chain-dotted line. The data of Seaports Administration of Ukraine were used for the analysis

To forecast the salary for 2020 and 2021, calculations were made, taking into account two assimilating risks - the risk of large-scale military actions and the risk of the drop in the value of the national currency. Due to the assimilative nature of each of the above risks, forecasting was performed separately for each of them. The forecasting results are shown in Table 1. The use of mathematical modeling methods revealed a non-obvious result. It is estimated that the impact on the volume of transportation from the risk of the national currency drop will be greater than the impact from military actions.

Table 1 - CT forecast data for 2020 and 2021

Types of cargo	**Forecast for 2020, thousand tons**			**Forecast for 2021, thousand tons**		
	O	P	Pessimistic	O	P	Pessimistic

		hostilities	currency exchange rate drop		hostilities	currency exchange rate drop
Containers	1190350	510200	920200	1351500	There is no	712200
Food loads	124	50	71	79	There is no forecast	51
Bulk cargo, except cereals	15200	9580	14200	16582	There is no	10900

Regarding the impact of the cargo type. Reduction of the volume of containerized cargo transportation in 2020 in the presence of assimilating risks in relation to the optimistic option by 21% -57.1%, in 2021 - by 47%. For food cargoes, respectively, by 42.7% - 58.7%, and by 35.5%. For bulk cargoes, respectively, by 6.6% - 39%, and by 34%. Thus, it is proved that the impact of assimilating risks will also depend on the cargo. And the most vulnerable will be container and food transportation, the least - bulk cargo.

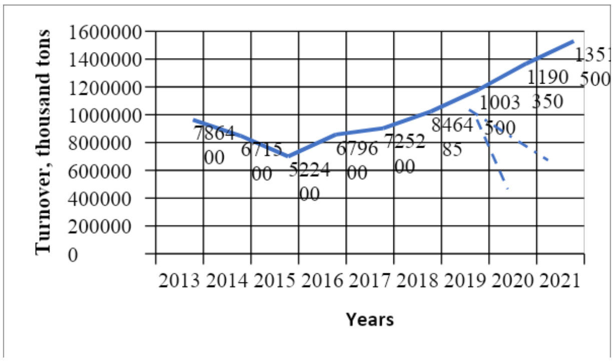

Fig. 2 - Container transportation volume forecast for 2020 and 2021

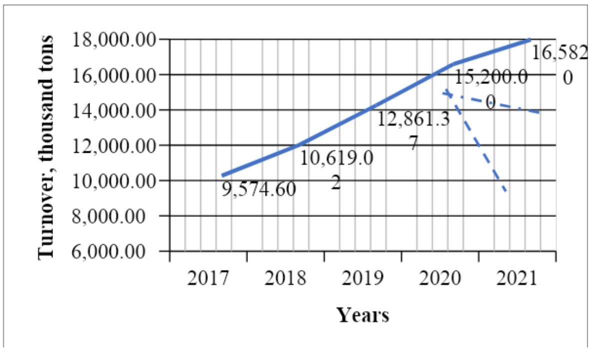

Fig. 3 - Bulk freight traffic forecast (excluding cereals) for 2020 and 2021

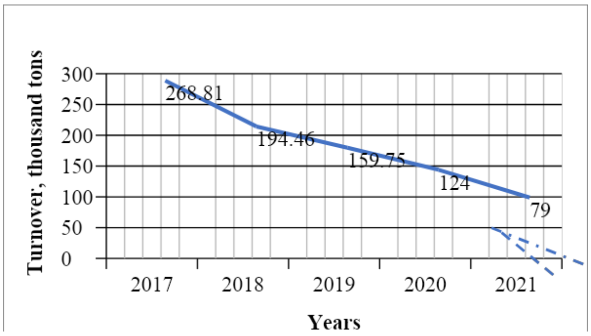

Fig. 4 - Estimation of the volume of transportations of food cargoes for 2020 and 2021

The forecast was made for the three types of cargo: container transportation, food cargo, bulk cargo with the exception of grain. It is these types of goods that correspond to the definition of combined transportations. These types of cargo have been subjected to pooled analysis in order to clearly illustrate the possible multifaceted effects of parameters specific to definite commodity markets.

In the optimistic variant of combined transportations, the tendency to increase their volume, more or less, depending on the types of cargoes, will be sustained. In the pessimistic scenario, shipment is forecast to decline to almost the level of 2015.

This confirms the argument that a definite number of the indeterminate parameters form the so-called "absorbing" risks whose impact on the result is crucial. In the case of absorbing risk, the overall impact of other risks will be negligible in comparison with it.

4. Conclusion

A universal algorithmic mathematical model is developed for the management of the CT and forecasting their results with the influence on transportation efficiency of not only fuzzy and stochastic parameters but also of indeterminate values. It has been proved by the considered example of forecasting the volume of combined transportation in Ukraine for the future periods that uncertain parameters can create absorbing risks, whose impact on the result may be greater than the impact of the whole set of other risks of the CT. Predicting such risks can have an impact on defining the transportation cost, volume estimation and the selection of CT routes. The use of the proposed mathematical model changes the approach to forecasting.

The proposed method of finding the best path that corresponds to the selected objective function using the appropriate mathematical apparatus has significantly reduced the computation time and the necessary computer resources.

Long-term forecasts allow to develop new routes in advance, test the use of other modes of transport and test them for certain cargoes before risk factors complicate transportation.

Pilot tests of the mathematical model have indicated that it can be used not only to make long-term forecasts, which requires some time, but also short-term forecasts in real time. This confirmed the possibility of using a mathematical model in the work of logistics companies to quickly change the routes of transportation in the best possible way.

The forecasts of volumes of container transportations, bulk cargoes (except grain) and food cargoes for 2020 and 2021 developed by use of mathematical model are already used in practical activity of the logistics companies.

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