



Management of Transport and Logistics System Based on Predictive Cognitive and Fuzzy Models

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Abstract. The article offers an approach to solving particular controlling problems that arise in the management of cargo transportation. The proposed approach makes it possible to predict the possibility of emergency situations during transportation and the duration of cargo transportation, on the basis of which the optimal route can be selected. To predict the occurrence of accidents, vehicle failures, and driver errors, a fuzzy cognitive model is constructed that allows taking into account a large number of heterogeneous factors. The forecast model for estimating the duration of transportation is based on the results of a survey of experts, and fuzzy logic is used to formalize expert estimates. A fuzzy hierarchical model is used to reduce the number of fuzzy products. The article also provides a methodological example showing the results of applying the cognitive approach to specific data.

Keywords: Controlling · Transport system · Cargo transportation · Optimal route · Cognitive model · Fuzzy model · Situational management

1 Introduction

The quality of production processes management, including transport and logistics, is given unflagging attention. One of the ways to solve the problem of improving management efficiency is controlling [1] a functionally separate direction in process management, aimed at the future state of the system/process. Controlling is one of the mechanisms of the market economy, which is designed to anticipate (evaluate in advance) the economic and commercial situation in order to take timely measures to optimize the activities of the business entity in order to achieve the set goals. Therefore, in order to avoid errors and ineffective solutions when using controlling, it is necessary to assess the difficulties and emergency situations in time and find ways to eliminate them in a timely manner.

The peculiarity of decision-making in the management of transport and logistics systems is that decision-making is carried out in conditions of uncertainty, lack of sufficient information about the possible states of objects and entities involved in the operation

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of such systems. Moreover, an important subject that affects the success of such systems is a person, for example, a dispatcher and/or a driver of a vehicle that performs cargo transportation. Professional qualities, personal, psychological, health status, possible reactions to situations that arise during the movement, etc.,—all these indicators undoubtedly have an impact on the possibility of emergency situations in the process of cargo transportation. The task of taking these indicators into account when making decisions is poorly formalized and, together with the need to take into account a large number of other heterogeneous indicators, requires the development of new approaches and the use of adequate methods.

Modern research on the management of transport and logistics systems actively uses artificial intelligence methods to account for possible uncertain situations. For example, fuzzy logic and fuzzy cognitive models are used to predict the success of transport projects related to the construction of new roads and to predict the consequences of the introduction of new transport technologies [2–5]. Artificial neural networks are used to evaluate vehicles in real-time tracking systems and during pre-flight checks [6, 7].

In this paper, we consider one of the tasks of controlling the management of transport and logistics systems; the task is of predicting the possibility of emergency situations during transportation using fuzzy cognitive maps, as well as forecasting the duration of cargo transportation using fuzzy models, on the basis of which a particular strategy for performing a transport and logistics operation can be adopted, in particular, the choice of the optimal route is made. It should be noted that most of the studies related to this topic are mostly devoted to specific aspects of this problem. This includes assessing the professional qualities of the driver [8], predicting the condition of the car [9, 10], etc. For a comprehensive analysis and prediction of risks arising in the process of cargo transportation, to take into account a large number of heterogeneous influencing factors, it is advisable to use cognitive modeling.

2 Cognitive Model for Predictive Assessment of Emergency Situations During Cargo Transportation

2.1 Application of Cognitive Modeling in the Management of Transport Systems

The cognitive approach is an approach to the study of processes, phenomena, objects in any subject area when the main attention is focused on the processes of representation, storage, processing, and interpretation of knowledge [11]. The cognitive approach is based on the construction of special (cognitive) models of the system under study and the use of a scenario approach. It allows to analyze possible scenarios for the development of situations (the states of the system and the environment), to assess the degree of achievability of the goals set when managing poorly structured systems. A cognitive map is a mathematical model of a system presented as a weighted oriented graph that allows describing the subjective perception of this system by a person or group of people.

The complexity of managing the transport and logistics system is due to the need for rapid management decisions in conditions of uncertainty, the presence of a large number of factors that affect the system; the lack of sufficient quantitative information about the behavior of the system, as well as a large number of factors that affect the

system; in addition, management decisions should allow predicting the possible risk of emergency situations that can lead to severe environmental consequences, human casualties, and material losses. Due to the specifics of transport systems, which are, in fact, poorly structured systems, it becomes appropriate to conduct a qualitative analysis of the possible consequences of decisions made using cognitive modeling.

In this paper, we have studied the possibility of using the cognitive modeling methodology to solve one of the tasks, that is forecasting the possibility of emergency situations in the process of cargo transportation based on the analysis of quantitative and qualitative information about internal and external factors that affect the possibility of an emergency, a failure in the operation of the vehicle and the delivery time of the cargo.

The features of functioning of any vehicle as a complex technical system are the following [12]:

- the vehicle functions only in conjunction with the person (driver), i.e., they form a human–machine system that belongs to the class of ergatic systems
- the operation of the vehicle, its system, and the driver is affected by a large number of non-stationary and subjective factors that are difficult to take into account.

The cognitive model allows to take into account heterogeneous, poorly formalized factors when predicting the possibility of emergency situations in the process of cargo transportation. It also makes it possible to analyze probable situations that may arise during cargo transportation depending on the state of the vehicle, the driver's state, the external environment, the route and cargo characteristics, etc.

2.2 Fuzzy Cognitive Model-Building for Predictive Assessment of Emergency Situations During Cargo Transportation

Fuzzy cognitive model for predictive assessment of emergency situations during cargo transportation [11, 13–15]:

$$\Phi = \langle G, Y, W \rangle$$

where $G = \langle V, E \rangle$ is an oriented graph (digraph), V is a set of vertices, and $V = \{V_l\} = \{P_i\} \cup \{T_j\} \cup \{G_h\}$ are the selected three groups that correspond to control, intermediate, and target vertices. Control vertices describe the current situation and, in turn, include the following groups of factors: the condition of the vehicle, the driver, external environment (weather, pavement quality, etc.), characteristics of the route, and cargo. The target vertices correspond to abnormal situations that may occur during cargo transportation, which may include an increase in the delivery time, the possibility of an emergency, and a failure in the operation of the vehicle.

$E = \{e_{ij}\}$, $i, j = \overline{1, M}$ is a set of arcs, M —total number of vertices.

$Y = \{Y^{V_l}\}$, $l = \overline{1, M}$ —set of vertex parameters V [the value of vertices T_h is a quantitative assessment of factors that describe the current situation (the vehicle in question, the selected driver, route features, cargo, etc.)]. The vertices take values from the interval

$Y^{P_i} \in [0; 1]$. Scaling of the natural values of the vertices $Y^{P_i^n}$ can be implemented using the formula:

$$Y^{P_i} = \frac{Y^{P_i^n} - (Y^{P_i^n})_{\min}}{(Y^{P_i^n})_{\max} - (Y^{P_i^n})_{\min}}$$

The value G_h is an assessment of the possibility of emergency situations; $Y^{G_h} \in [0; 1]$ or $Y^{G_h} \in [-1; 1]$.

Effects weights $W = \{w_{ji}\} (i = \overline{1, M}, j = \overline{1, M})$ between each pair of vertices take values from the interval $[-1; 1]$. Positive weight value w_{ij} indicates that there is a direct connection between vertices: the increase in the value of the vertex V_i leads to an increase in the value of the vertex V_j , and vice versa, the decrease in the vertex value V_i reduces the value of the vertex V_j . Negative weight value w_{ij} indicates that there is feedback between vertices: the increase in the value of the vertex V_i reduces the value of the vertex V_j , and vice versa, the decrease in the vertex value V_i leads to an increase in the value of the vertex V_j .

Calculation of the forecast estimation of occurrence of emergency situations in the process of cargo transportation includes the following stages:

- Stage 1 Building a cognitive model.
- Stage 2 Setting the initial values of the control vertices.
- Stage 3 Recalculates the values of all vertices (except for vertices corresponding to performers). Model of cognitive map calculation stages [11]:

$$Y_i(t + 1) = f \left(k_1 \cdot Y_i(t) + k_2 \cdot \sum_{j=1}^M Y_j(t) \cdot w_{ji} \right), \tag{1}$$

where $Y_j(t + 1)$ $Y_j(t)$ are the values of the j th vertex at the calculation stage $t + 1$ and t ; w_{ji} is the weight of the connection between vertices V_j and V_i ; $f(\cdot)$ is a non-linear, monotonically increasing function that converts the value of an input argument in the interval $[0;1]$ or $[-1;1]$, and this determines the range of possible values of the target vertices; k_1 and k_2 characterize the contribution of the corresponding components to the calculation of the new vertex value ($0 \leq k_1 \leq 1, 0 \leq k_2 \leq 1$). Calculation using the Formula (1) is carried out until the values of all vertices stop changing.

Figure 1 shows a fragment of a cognitive model for predicting the occurrence of emergency situations during cargo transportation. Table 1 shows a description of the vertices of this cognitive map and an interpretation of the maximum value of the vertices corresponding to one.

3 Predictive Estimation of the Duration of Cargo Transportation and Selection of the Optimal Route

The deviation of the delivery period from standard can be caused by a whole set of factors, some of which are given in the previous section of this article. It is possible to estimate

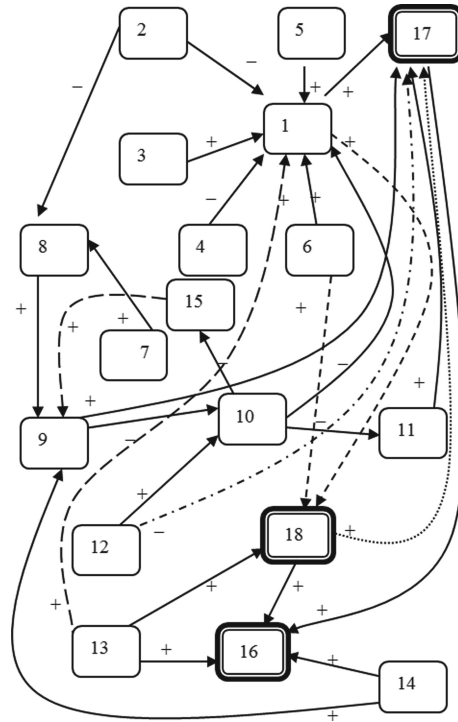


Fig. 1. Fragment of a cognitive model for predictive assessment of emergency situations during cargo transportation.

the approximate delivery time by interviewing experts or by using the cognitive model, discussed above, to assess how much the delivery time may increase depending on the current situation. Another approach to formalizing expert evaluations that allows using qualitative evaluations can be based on fuzzy logic. To calculate the forecast estimate of the delivery time from one point to another point, a fuzzy model can be built using fuzzy products of the form:

$$\text{If } A_1 \text{ is } \tilde{A}_1^{i_1} \text{ AND } \dots \text{ AND } A_n \text{ is } \tilde{A}_1^{i_n} \text{ Then } T \text{ is } \tilde{T}_1^{i_1},$$

where A_j ($j = \overline{1, n}$) are input linguistic variables corresponding to influencing factors (\tilde{A}_j^{ik} are values of linguistic variables A_j), T is an output linguistic variable “Delivery Time” (\tilde{T}^{i_1} are values of a linguistic variable T).

For a large number of input variables, it is advisable to build fuzzy hierarchical models in order to reduce the number of rules [15]. A possible way to build such a model in the case of four input linguistic variables is shown in Fig. 2 (V_1 and V_2 are intermediate linguistic variables, RB is a rule base).

If there are different routes from the starting point to the final point, the obtained forecast estimates of the duration of transportation between possible route points allow to find the optimal route (according to a complex criterion that takes into account a

Table 1. Some vertices of the cognitive map for predictive assessment of emergency situations in the process of cargo transportation.

Vertex number	Vertex name	Vertex number	Vertex name
1 (intermediate vertex (initial value is zero))	Driver errors in the handling of the vehicle (1—a large number of errors)	10	The quality of the road surface (1—road surface is good)
2	The experience of the driver (1—a long experience)	11	Traffic flow rate on the route (1—high traffic intensity)
3	Number of road accidents caused by the driver (1—a large number of road accidents)	12	Weather conditions during transportation (1—good weather conditions)
4	The level of the driver's health (1—the driver is absolutely healthy)	13	Number of vehicle breakdowns (1—a large number of breakdowns)
5	Number of road accidents caused by a vehicle malfunction (1—a large number of road accidents)	14	Restricting and prohibiting signs on the route (1—a large number of limiting and prohibiting signs)
6	The service life of the vehicle (1—a long service life)	15	The duration of the route (1—long route duration)
7	Cargo volume (1—large cargo volume)	16 (target vertex)	Delivery time (1—significant increase in delivery time)
8	Nature of cargo (1—a dangerous cargo)	17 (target vertex)	Occurrence of emergencies (1—greater possibility of an emergency)
9	The speed limit (driving style) (1—extreme driving mode)	18 (target vertex)	The failure of the vehicle (1—greater possibility of vehicle malfunction)

complex of qualitative and quantitative factors). In this case, the optimal route will take into account the possible risks of emergency situations in the process of cargo transportation, i.e., the elements of situational management will actually be used [16].

In a more advanced version, it is possible to embed a special decision support subsystem in the architecture of on-board information and control systems for modern and advanced heavy-duty vehicles [17].

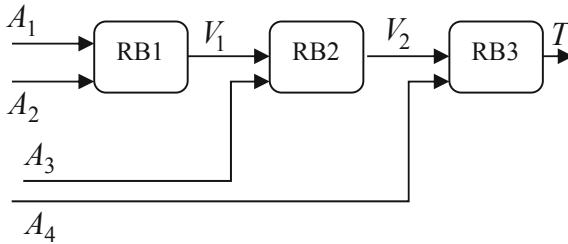


Fig. 2. Variant of implementation of the fuzzy hierarchical model.

4 Methodological Example of Predictive Assessment of Emergency Situations in the Process of Cargo Transportation

In this section, we will study some of the situations that may occur when organizing cargo transportation, and assess the possibility of emergency situations based on the cognitive map shown in Fig. 1.

Let the influence weights between map vertices have the following values:

$w_{21} = -0.8, w_{21} = -0.8, w_{31} = 0.7, w_{41} = -0.4, w_{51} = 0.5, w_{61} = 0.4, w_{10,1} = -0.4, w_{1,17} = 1, w_{1,18} = 0.7, w_{13,1} = 0.4, w_{6,18} = 0.7, w_{78} = 0.8, w_{28} = -0.8, w_{89} = 0.8, w_{15,9} = 0.8, w_{9,10} = -0.8, w_{9,17} = 0.8, w_{14,9} = 0.6, w_{10,15} = -0.8, w_{10,11} = -0.4, w_{12,10} = 0.4, w_{11,17} = 0.4, w_{12,17} = -0.5, w_{13,16} = 0.5, w_{13,18} = 0.8, w_{14,16} = 0.5, w_{18,16} = 1, w_{17,16} = 1, w_{18,17} = 0.8.$

As a function $f(\cdot)$ in (1) a hyperbolic tangent was chosen to calculate the vertex values, $k_1 = k_2 = 0.9$ B (1).

Let us find the values of the target vertices for the “ideal” situation corresponding to the best values of the managed vertices. In this situation, we have the following values of the corresponding vertices: $Y^{V_2} = 1, Y^{V_3} = 0, Y^{V_4} = 1, Y^{V_5} = 0, Y^{V_6} = 0, Y^{V_7} = 0, Y^{V_8} = 0, Y^{V_9} = 0, Y^{V_{10}} = 1, Y^{V_{11}} = 0, Y^{V_{12}} = 1, Y^{V_{13}} = 0, Y^{V_{14}} = 0, Y^{V_{15}} = 0.$ The qualitative description of this situation is as follows: the driver has a long driving experience, good health, and has not been involved in road accidents, observes the rules of the road, the route is easy, the weather conditions for the trip are good, etc. Changes in values during the calculation process and established values of target vertices V_{16}, V_{17}, V_{18} are shown in Fig. 3a.

In the “worst” situation, we have the following values of the corresponding vertices: $Y^{V_2} = 0, Y^{V_3} = 1, Y^{V_4} = 0, Y^{V_5} = 1, Y^{V_6} = 1, Y^{V_7} = 1, Y^{V_8} = 1, Y^{V_9} = 1, Y^{V_{10}} = 0, Y^{V_{11}} = 1, Y^{V_{12}} = 0, Y^{V_{13}} = 1, Y^{V_{14}} = 1, Y^{V_{15}} = 1.$ Changes in the values during the calculation and the established values of the target vertices are shown in Fig. 3b.

Figure 4 shows the changes in values during the calculation process and the established values of target vertices for an arbitrary situation with the following values of managed vertices: $Y^{V_2} = 0.9, Y^{V_3} = 0.3, Y^{V_4} = 0.7, Y^{V_5} = 0.3, Y^{V_6} = 0.9, Y^{V_7} = 0.6, Y^{V_8} = 0.6, Y^{V_9} = 0.4, Y^{V_{10}} = 0.6, Y^{V_{11}} = 0.6, Y^{V_{12}} = 0.8, Y^{V_{13}} = 0.1, Y^{V_{14}} = 0.2, Y^{V_{15}} = 0.5$.

It is obvious that the obtained values correspond to the expected estimates of the considered situations.

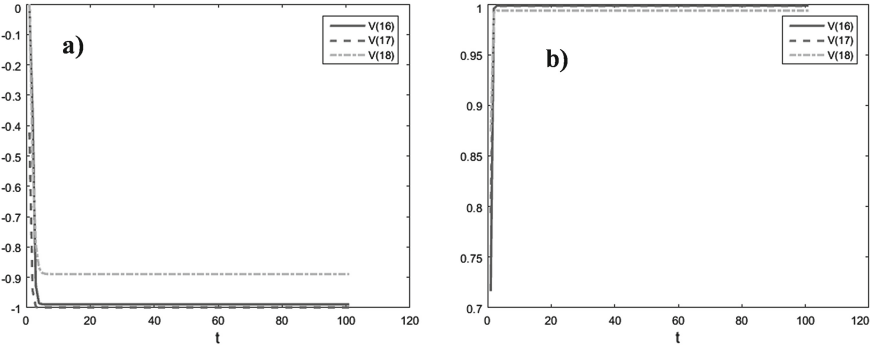


Fig. 3. **a** The value of the target vertices for the “ideal” situation; **b** target vertex values for the “worst-case” situation.

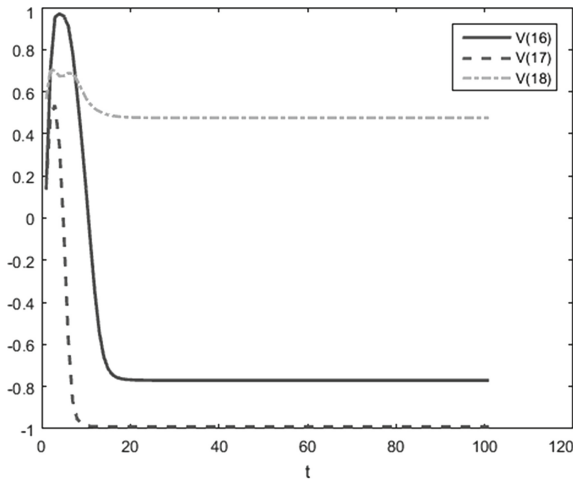


Fig. 4. Values of target vertices for an arbitrary situation.

5 Conclusion

The cognitive approach makes it possible to forecast the occurrence of emergency situations, taking into account a large number of heterogeneous influencing factors, and to improve the quality of decisions made in the management of cargo transportation. One of the advantages of using fuzzy cognitive maps for this problem is the ability to formalize and describe very complex situational constructions. At the same time, the implementation/configuration of cognitive models is limited only by our capabilities/limitations in identifying a sufficient amount of numerical data that corresponds to real situations that arise in the process of cargo transportation. The proposed approach can also be applied when selecting drivers and vehicles for cargo transportation. The direction of further research is to expand the set of factors taken into account, improve the methodology for building cognitive models based on the results of a survey of experts and retrospective data, and explore the possibilities of using different types of cognitive models.

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