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# Predicting and Preventing Transport Accidents with Fuzzy Relationships

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## ABSTRACT

The problem of traffic safety is relevant and related to the growth of emergency and uncertain situations - both for automobiles and pedestrians. Intelligent traffic management systems, expert systems are being introduced. But relevant information-logical (mathematical) support is required. Fuzzy sets and fuzzy logic have become most effective. A systematic approach is adopted with analysis of self-organization possibilities of flows and situational modeling of heterogeneous transport systems. With selection of optimal (accident-free) strategies, goals and solutions. It is also necessary to improve the quality and level of transport logistics, ensuring the competitiveness of transport companies with efficient business processes. In the work, the fuzzy-multiple and fuzzy-logical problem of prediction of accidents is formalized, investigated. The task of developing an expert system of risk assessment and classification of risk situations is considered. Pre-accident (emergency) situations are classified into five categories of situations: "does not lead to an accident" (A); "little impact on accidents" (B); "subject to accident rate" (C); "preemergency" (D); "leads to an accident" (E). Each class has its own indicators, such as road situations. In addition to the system analysis of the problem, a procedure for fuzzy situation assessment is proposed.

**Key words**: transport, flow, accident, fuzzy sets, fuzzy logic, simulation,preventing.

## 1. INTRODUCTION

IT-infrastructure of transport services changes logistics, and also risks in it concerning key business processes. They are transferred from the traditional coordinate system (path, time, and cost) to new dimensions: optimization, control, information.

Optimization identifies hidden potential, resources that give competitive advantage to business processes. For example, dispatch for logistics is no longer a "by-product", but a key informative business process.

Russian transport enterprises need digital infrastructure, because the territory is branched. Transport logistics management of the "digital" transport industry is focused not only on optimization of quantitative (as a rule, financial) parameters, but also qualitative (comfort, informatively, flow, etc.).

The transport company purposefully, by activating backward links with the environment, seeks not only to reduce costs, but also to ensure security by using modern technologies and methodologies of information processing and analysis.

Safety, time-efficient and traffic safety issues are relevant in traffic flows [1]. The problem is compounded by uncertainties, particularly the risk of accidents. Especially in vehicle maneuvering and poor visibility [2].

Reliability of transport systems is determined by safety for pedestrians also [3].

Intelligent traffic management is based on knowledge bases and models, expert systems [4]. The problem is relevant, requires the use of modern information-logical and mathematical apparatus, fuzzy sets and logic.

Complex (algorithmically, information, interface, technological) support of transport infrastructure, system approach in estimation of complexity of streaming tasks is required. This problem is comparable in complexity to the problems of thermodynamic systems, their possibilities of self-organization.

Such a task is formalized and investigated using an apparatus of fuzzy sets and logical connections.

## 2. THEORETICAL BASES

With the growth of the possibilities of distributed processing of heterogeneous transport information (in particular, in cloud structures), the list of provided services, assistance schemes are also expanded. For example, services adapted in automated mode, required in emergency situations (diagnostics, repair, re-formation of cargo, etc.).

It’s possible to form a set of standard and effective business processes, solutions taking into account their cost, popularity and loyalty of the client, resource costs, etc. Not only transport, technological and financial difficulties began to affect, but also difficulties of logic and algorithms, selection of criteria (comparison of strategies), functions of goals (decision-making).

The problem of developing and implementing an effective transport strategy is important and relevant in conditions of multicriterial choice, both of the vehicle and of the route.

It's necessary to use various types of relations: "the driver - the driver", "the driver - the road", "the driver –the transport company", "the company - the company", etc.

There’s also a need to improve the quality of service and transport logistics. Therefore, only competitive transport organizations survive in certain segments of the logistics services market, with efficient business processes and sufficient evolutionary potential.

The transport services market is both multi-criterion and hierarchical.

The main hierarchy levels are:

1) level of vehicle, driver (choice of speed and even way, insured, repair, etc.);
2) the level of the transport company (private, public, with state participation);
3) market level, industry segment (autonomy, adaptability, self-regulation, etc.).

Competitiveness isn't the main one in solving the problem of efficient provision of transport services, the company can be viable and without effective market indicators (demand, supply, capital, etc.). There are examples of small companies competing successfully in the market and finding their niche thanks to specific sets of competitiveness parameters, reaching the level of self-organization.

For this purpose it's necessary to turn not only to re-engineering of transport infrastructure, but also to system analysis, expert and analytical systems. The variability of processes, uncertainty of states and decision conditions should also be taken into account. Intellectual systems based on fuzzy computer science and mathematics are needed [5].

The emergency situation can have many reasons - unprofessional driver, poor technical condition of the vehicle, bad weather conditions, poor road surface, etc. We will classify them into several groups.

Pre-accident and emergency situations will be integrally classified by classes:

1) "not leading to accidents" (A);
2) "weakly affected in accidents" (B);
3) "with accident rates" (C);
4) "severely affected, pre-emergency" (D);
5) "leading to accidents, emergency" (E).

It is possible to classify in another scale.

At each class - the indicators. Indicators on which we draw a conclusion about a situation on the road.

Changes, transition to a more dangerous class are possible as a result of, for example, long-term operation of the car, road surface, as well as impacts (unplanned action, etc.).

It's necessary to draw up a database, based on it - a knowledge base, which allows to classify the state of the situation, as well as to develop an expert system of diagnostics of the state. Each situation, each factor leading to the accident, needs to be taken into account [6].

Special attention is paid in this process to dynamically introduced "noise," for example, traffic congestion, weather anomalies and unauthorized failures of transport or control flow of the system.

## 3. METHODOLOGY

Set the membership function [7] in exponential form:

$$M(x) = e^{-k(x-2)^2},$$

where k is the fuzzy degree parameter and r is the position parameter (on the numerical axis). These parameters are specified by experts and heuristically, for example, taking into account the δ-tolerance of uncertainty (100-δ)%. The parameter r is the midpoint of the fuzzy interval.

For example, for 5% of the width (dictated by the Student criterion [8]) of the uncertainty band of the transport situation, you can record the function of belonging:

$$\mu(x) = \begin{cases} e^{-3{,}007(x-17{,}5)^2}, & x \le 17.5, \\ e^{-2{,}691(x-18{,}5)^2}, & x \ge 18{,}5, \\ 1.0, \quad 17.5 < x < 18.5. & \end{cases}$$

For recognition capabilities, you must have a knowledge base based on output rules, product rules of type:

if (< condition > and (or) < condition >) then
"The situation falls into Class A (B, C, D, and E)".

For example, you use view rules:

P1: if the parameter values are better than the A state parameters, the state is not abnormal;

P2: if at least one of the taken into account parameters is worse than the emergency situation, the situation is emergency, etc.

Situation A (B, C, D, E, F) is determined at the same time from several values of parameters to be considered, with which linguistic parameters and operations of their binding are associated, for example,

1) and: $\mu^{and}(x) = \min(\mu_1(x), \mu_2(x))$;
2) or: $\mu^{or}(x) = \max(\mu_1(x), \mu_2(x))$,

where$\mu_{1(2)}(x)$(x) is a function of belonging to condition 1 (2) at current parameter values.

To identify the situation (belonging to class number k) we consider the function of belonging to the situation to class:

$$\mu_k = \max_k \min_j \sup_{X_j} (\min\, (\mu_j(x),\ \mu_{kj}^{and}(x), \mu_{kj}^{or}\ (x))) \quad ,$$

where$\mu_j(x)$is a function of belonging to the j-th parameter and$\mu_{kj}$is a function of belonging to the communication (And, Or, Not) by the j-th parameter for classnumber k.

## 4. RESULTS AND DISCUSSION

Decision-making in conditions of uncertainty requires new methods, information structures, models. The main thing is to highlight and classify the capabilities of flows and quality analytics. Fuzzy-logical solution is a solution intelligent, optimizing, often visualized and attractive for feedback and their tracking.

The effectiveness, reliability depends on early diagnosis and forecasting of the situation without ambiguity. For assessment of quantitative reliability we use as traditional indicators (profitability, profitability, etc.) and heuristic and expert opinions of the decision-maker and an intellectual system.

For this purpose we enter X, Y, Z, T - linguistic variables [9] with ordinary terms:

1) $X_1, X_2, X_3, X_4$- risks (low, satisfactory, large, unacceptably significant);
2) $Y_1, Y_2, Y_3$- risk mitigation costs (low, optimal, unacceptable);
3) $Z_1, Z_2, Z_3, Z_4$- reliability (low, satisfactory, good, excellent);
4) $T_1, T_2, T_3, T_4$- solution with fuzzy values from [0;1] (Positive; "Yes" rather than "No"; "No" rather than "Yes"; Negative).

You will need to identify the ownership functions for these fuzzy terms and its relations.

It's enough for us to define approximate functions:

1) $\mu_{X_i}, i = 1, 2, 3, 4$, for example, for given parameters a, b -

$$\mu_{X_1} = (1 \wedge (x \le a_1)) \vee (0 \wedge (x \ge b_1)) \vee (\left(\frac{b_1 - x}{100}\right) \wedge (a_1 \le x \le b_1))$$

2) expenses $\mu_{Y_i}, i = 1,2,3$;
3) reliability $\mu_{Z_i}, i = 1,2,3,4$;
4) decisions $\mu_{T_i}, i = 1,2,3,4$.

The graphs of these accessory functions are broken lines.

The expert knowledge base is formed by rules of output of the following type:

$$\text{if}((x \in X_i) \cap (y \in Y_j) \cap (z \in Z_k)) \text{ then } (t \in T_t)$$

or

$$\text{if}((x \in X_i) \cup (y \in Y_j) \cup (z \in Z_k)) \text{ then } (t \in T_t).$$

The knowledge base and associated output system (model) can solve a number of problems:

1) assess the state of the transport system as a whole;
2) assess the state of the transport system or transport cluster section;
3) assess the system status for each vehicle.

The expert system, implemented on the basis of the method described above, will allow interactively assessing risks, states and choosing the mode of movement, redistributing flows.

For real tasks it’s necessary to use a bank of ownership functions, for example, $\Lambda$-, $\pi$-, $Z$-, $S$-functions[10].

The theory of fuzzy relations allows solving optimization problems and logistics. But qualitative monitoring here often and significantly affects the results of forecasting, assessment.

For efficient classification, we break down the original objects (events) according to the specified proximity measure (target function). Then we identify the transport event belonging to the class of events entered above (for example, accidents).

If S is a set of events (movement strategies or logistics), then we enter relationships:

1) intersections $s_1 \wedge s_2$events (e.g. unresolved overtaking and permitted speed);
2) combining $s_1 \vee s_2$ events (e.g. overtaking and large freight transport on the opposite lane);
3) inversions of $\bar{s}$events (for example, end of the dangerous site of a way);
4) fuzzy minimum, maximum or inversion (for example, the choice of "preference" for a traffic violation with the danger of oncoming transport or a pedestrian impact);
5) similarities$s_1 \sim s_2$(e.g. two emergencies).

Membership functions can be determined through Gaussian functions that are good for performance evaluation. For example, use the functions "high rating" ($\mu_5(x)$)and "low rating" ($\mu_1(x)$) of the type:

$$\mu_5(x) = e^{-3,5(5-x)^2},$$

$$\mu_4(x) = e^{-3,5(4-x)^2},$$

$$\mu_3(x) = e^{-3,5(3-x)^2},$$

$$\mu_2(x) = e^{-3,5(2-x)^2},$$

$$\mu_1(x) = e^{-5,5(1-x)^2}.$$

Factors, conditions of high danger of accidents on busy highways are more difficult to analyze and control - the flow of processed information is large [11]. Statistical methods are effective here [12].

Transport organizations are developing the following main infrastructure elements (technologies) to reduce the risk of accidents:

1) computer vision;
2) robotic tracking in streams;
3) high-speed real-time identification of objects (via photo-video);
4) recognition regardless of distance and interference;
5) self-training systems;
6) management of brain activity;
7) industrial Internet;
8) IoT (Internet of Things);
9) sensors capable of detecting breakage and automatically eliminating it.

Leverage predictive analytics [13], cloud CRM [14].

## 5. CONCLUSIONS

For transport tasks that are poorly formalized, structured approach and tools proposed by us are promising. Especially, in conditions of insufficient and unclear awareness of the transport system, dynamic change of its parameters.

It’s also important that the method does not attract topological information about the transport network and is universal.

If developed according to the proposed procedure and methodology, a neuro-system that uses fuzzy transport relations, it will allow to divide into equivalence classes and allocate taxa taking into account transport characteristics of the region (up to the manner of driving, up to legal support). The procedure proposed in the work can be developed.

The evolution of multilevel transport logistics structures will create a situation in which the probability of stability of work will be higher and accidents - less.

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