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FUZZY ALGORITHM FOR SITUATIONAL CONTROL OF URBAN TRANSPORT TRAFFIC

Annotation. The problem of operational dispatching control of urban transport is considered on the example of fixed-route taxis. The analysis of passenger traffic is carried out on the mathematical apparatus of the theory of queuing systems, within which a graph of states is constructed and ratios are obtained to evaluate the main indicators of the quality of minibus taxis. Due to the presence of information uncertainty in the work of urban transport, an algorithm of fuzzy situational management is proposed, which is the basis of intellectual DSS. For an optimal transition from the current situation to a situation that meets the new operating conditions, in the sense of the selected criterion, it is proposed to use the dynamic programming method.

Keywords: urban transport, operational dispatch control, minibus taxi, state graph, emergency situations, information uncertainty, intelligent DSS, fuzzy situational control algorithm, optimal transition to a fuzzy network.

Introduction

Due to the constant growth of cities in terms of population and territory, the volume of passenger traffic and traffic is sharply increasing. A lot of attention is paid to the study of transport infrastructure in scientific works, but the current problems of the functioning of various types of transport in large cities remain not fully covered. First of all this concerns the great uncertainty in the current information about the movement of transport and their work in the event of emergency situations. Hence, the development of a fuzzy algorithm for situational control of urban transport traffic is an extremely urgent task [1-3.6-8].

Problem statement

It known [7] that the decision-making task (DMT) can represented as:

$$DMT = \langle T, A, Q, Y, F, G, D \rangle, \qquad (1)$$

where : T – problem statement; A – the set of alternatives; Q – set of selection criteria (evaluating the effectiveness of solution options); Y – multiple methods for measuring relationships between options; F – mapping a set of valid options to a set of ratings; G – the system preferences of experts; D – a decision rule that reflects the preference system.

Assume that the current situation that has developed in the process of urban transport operation described as a fuzzy situation of the following type [9]:

$$S_{TEK} = \{M_{s_i}(x_i)/x_i\}, x_i \in X, \qquad (2)$$

$M_{s_i}(x_i)$ – function of belonging to a linguistic variable x_i, that characterizes the current situation S_{TEK}.

Also, assume that for each linguistic variable x_i corresponds to the j -th term of the set of terms in the knowledge base. Then the formula (2) can written as:

$$S_i = \left\{M_{M_{S_i(x_i)}}(T_j^j)/T_j^j\right\},\ j = \overline{1, M},\ i = \overline{1, N}, x_i \in X, \quad (3)$$

T_j^j – j-th term i-th linguistic variable.

To determine the current state of urban transport networks it is necessary to compare this fuzzy situation with each fuzzy situation from a certain set of existing situations in the knowledge base of this subject area $S = (S_1, S_2, \ldots, S_K)$. The result of the comparison should be a dispatcher's decision on the strategy for further urban transport management with the involvement of IDSS. If the current situation is «regular», the control implemented automatically according to the existing algorithm for this situation. If occurs an «emergency» situation, the IDSS will help you choose a management strategy that is close to this situation, or, if one is not found, form a new management strategy

Analysis of existing solutions

The growing interest in solving the problem of organizing the movement of urban transport is caused by the complication of the scheme of transport flows of the city, increased competition and an increase in emergency situations arising in the process of movement. To date, effective management of urban transport is unthinkable without the use of intelligent control systems [1-4]. In most cases, the control and management of the passenger transportation process is carried out by a dispatcher [2,6].

The movement of urban transport at the this time is characterized by the transience of changes in road situations, the lack of complete information about the current situation on the route, the presence of a large number of uncertainties when receiving current information, the inability to build a reliable forecast of the situation for a long time interval. All this requires a lot of psychophysiological stress from the dispatcher when making the right operational decisions [3,4].

Passenger traffic analysis

Urban transport is a complex branched queuing system. Due to the uneven load of urban transport, it is difficult to predict the optimal modes of its operation. In this regard, there is a problem of ensuring such management of the modes of operation of urban transport, which would simultaneously reduce the operating costs for its maintenance and meet the needs of passengers in transportation.

The complexity of solving this problem is associated with the lack of a complete mathematical model of passenger traffic in large cities for the totality of all types of urban transport [7]. This task is very complex and still does not have a single effective solution. Therefore, this paper proposes a mathematical model for a special case of passenger traffic, namely for the operation of fixed-route taxis.

It is proposed to formalize the transportation of passengers by minibus with a model of a queuing system with group passenger service.

Transportation in this transport is carried out in groups with r passengers. When the minibus is released, it takes a group containing exactly r passengers from the queue and starts serving them at the same time. The service time of this group is selected randomly in accordance with the exponential distribution law with the parameter μ. If less than r requirements have accumulated in the queue by the time the serving minibus is released, then the minibus waits until the full group of passengers is typed, and only then begins group service, etc. Applications are received in the form of a simple stream with an intensity of λ.

Since the idle time of a minibus in cases when there are fewer passengers than when fully loaded is wasteful, we consider a real system in which a minibus serves as many passengers as it stands in a queue. The state of this system will be determined in accordance with Fig.1 [9,10].

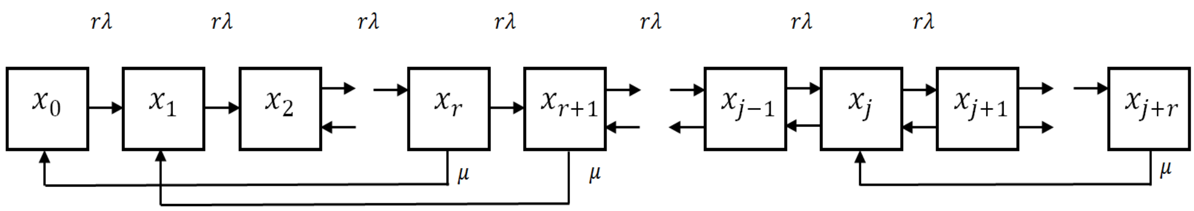

Figure 1. Graph of the state of the system with group maintenance

It can be seen from Fig.1 that all states, with the exception of the initial state x_0, are characterized in the same way: the transition to this state is possible from the left neighboring state when a new passenger appears (requirements) and from the neighboring states on the right at the end of group transportation. This leads to the following system of equations for stationary probabilities if there are requirements in the system:

$$(\lambda + \mu)p_k = \mu p_{k+r} + \lambda p_{k-1}, k \geq 1,$$
$$\lambda p_0 = \mu(p_1 + p_2 + \cdots + p_r). \quad (4)$$

Applying the method of generating functions [9], we define

$$P(z) = \sum_{k=0}^{\infty} p_k z^k. \quad (5)$$

Multiplying by z^k and introducing $P(z)$, we get

$$(\lambda + \mu)[P(z) - p_0] = \frac{\mu}{z^k}[P(z) - \sum_{k=0}^{r} p_k z^k] + \lambda z P(z). \quad (6)$$

Resolving this equality with respect to $P(z)$, we have

$$P(z) = \frac{\mu \sum_{k=0}^{r} p_k z^k - (\lambda+\mu)p_0 z^k}{\lambda z^{r+1} - (\lambda+\mu)z^k + \mu}. \quad (7)$$

The negative term in the numerator of the right side of the last equality can be written as [10]

$$-(\lambda + \mu)p_0 z^r = -\mu z^r \sum_{k=0}^{r} p_k. \quad (8)$$

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Therefore, we get finally

$$P(z) = \frac{\mu \sum_{k=0}^{r-1} p_k (z^k - z^r)}{r\rho z^{r+1} - (1+r\rho) z^r + 1}. \quad (9)$$

where $\rho = \lambda / \mu \ \ r$-the *utilization* factor.

Thus, in this model can be served simultaneously r of requirements during the time interval of the average duration $1/\mu$ of seconds.

Since the resulting expression is inconvenient for practical use, it can be simplified and reduced to the form [10]:

$$p_k = \left(1 - \frac{1}{z_0}\right)\left(\frac{1}{z_0}\right)^k. \ k = 0,1,2, \ldots \quad (10)$$

The last expression characterizes the distribution of the number of applications in a system with group service. Based on it, you can calculate a number of indicators of the system with group service. It should be noted that in the case of a flow of requirements, when the model does not meet the Markov process, a simulation model is used.

As mentioned earlier, to ensure high efficiency of operational decisions taken by the dispatcher to control the movement of urban transport, including fixed-route taxis, the use of an intelligent automated decision support system (IDSS) is required [3,11]. It improves the efficiency of urban passenger transport and reduces economic costs. With the help of the automated control system, the dispatcher can quickly respond to the typical emergency situations that have arisen and make decisions that are adequate for the given situation (Fig. 2) [4, 6].

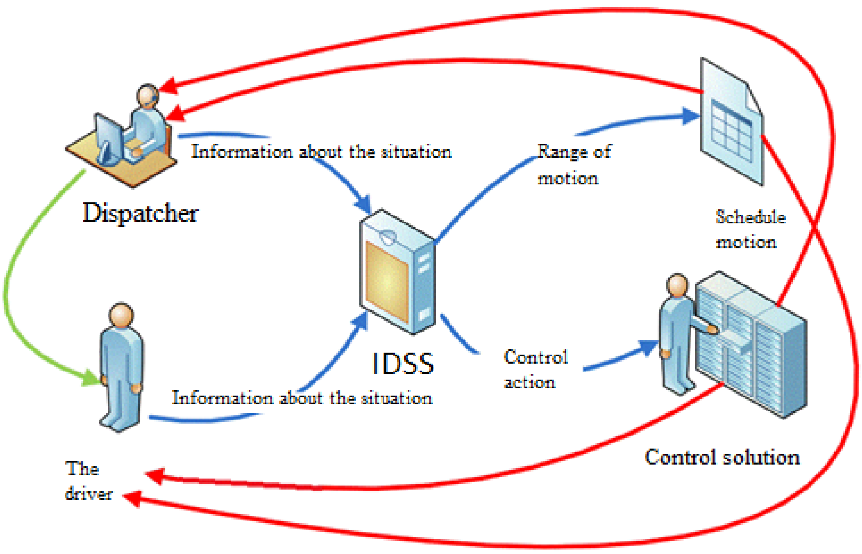

Figure 2. Information flows in IDSS

Passenger traffic analysis

Due to the large number of information uncertainties about the situations that have arisen in the work of urban transport, the approach based on fuzzy situational management is the most effective [5,12]. In this regard, the paper proposes an algorithm for fuzzy situational control (Fig. 3), for a dispatcher for managing various types of urban transport. The use of this algorithm can significantly improve the efficiency of urban transport. The algorithm of fuzzy situational management of urban transport is given below (Fig. 3).

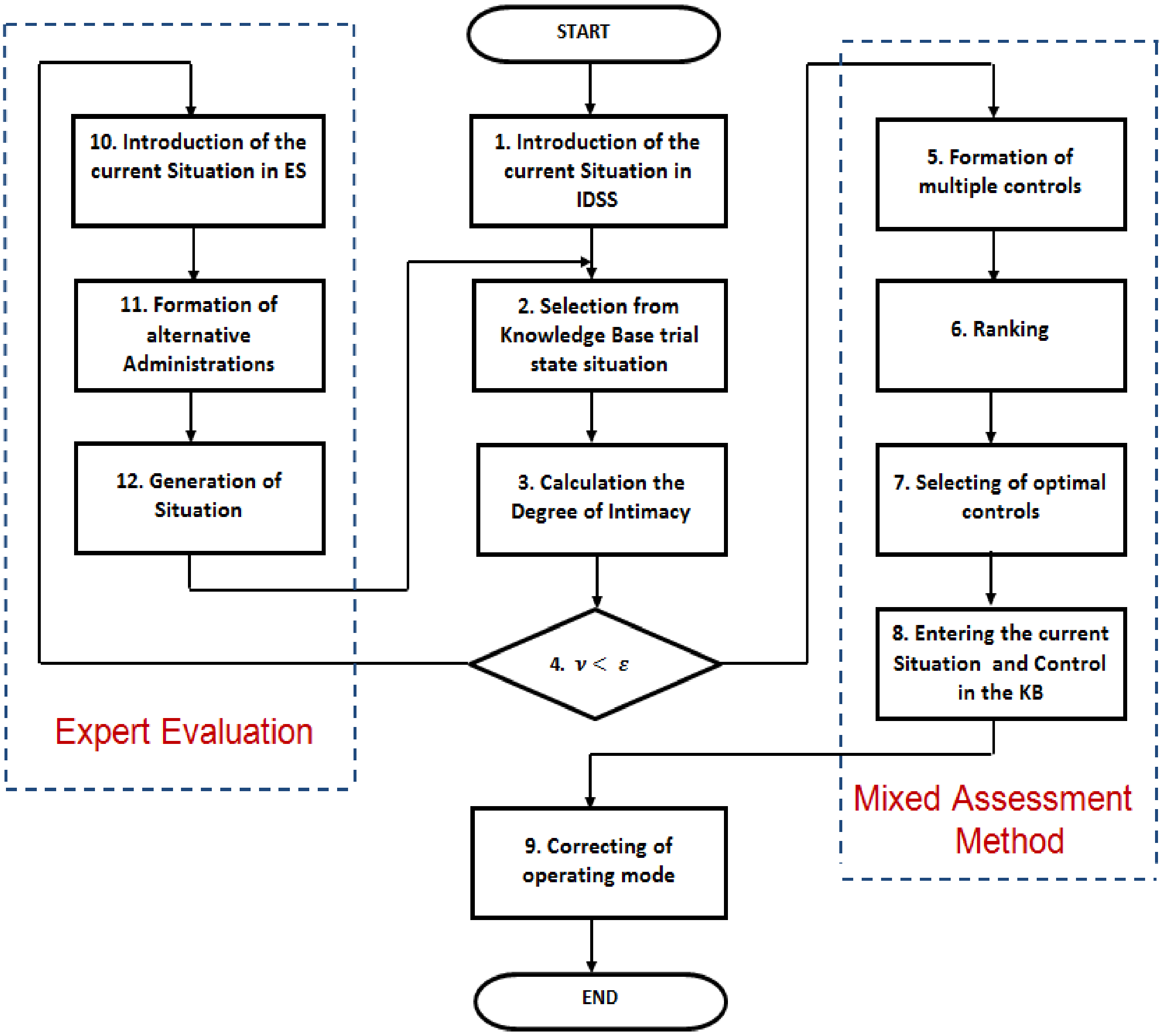

Figure 3. Algorithm of fuzzy situational management of urban transport

In *block 1*, information about the current traffic situation is entered. At the same time, some of the information is entered into *IDSS* automatically from video cameras. In the most general case, information about the current situation will be characterized by both quantitative and qualitative parameter values.

In block 2, the current situation is compared with a set of typical situations that are in the knowledge base (*BZ*) and are characterized by the same set of parameters as the current one. Thus, this

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block contains a certain set of possible situations for which it is possible to calculate the degree of proximity to the current situation.

In *block 3*, the degree of proximity of the current situation and similar typical situations from *block 2* is calculated.

Block 4 defines a typical situation that is closest to the current one.

In *block 5*, the formation of control solutions corresponding to the typical situations selected in *block 4* is carried out.

In *blocks 6,7* the effectiveness of control actions is ranked in descending order in a subset of selected typical situations and the optimal one is determined among them.

In *block 8*, the optimal control and the corresponding situation are entered as a typical in the knowledge base on the functioning of urban transport.

It should be noted that *blocks 5-8* are implemented on the mixed assessment method proposed by the authors in [12].

In *block 9*, the traffic mode is adjusted taking into account the current situation.

In *block 10*, the current situation is placed in the expert environment (*ES*) and the knowledge base of this subject area.

In *block 11*, possible control actions are requested from experts in this subject area, which are also placed in the knowledge base.

In block 12, experts in this subject area are asked for possible situations that can lead to the choice of one or another control action generated by them and are also entered into the knowledge base.

Modeling optimal transitions in a fuzzy situational network

Let be a weighted oriented graph (Fig.4) is a fragment of a fuzzy situational network (Fig.1). Necessary to transfer from the «regular» situation S_1 to the «regular» situation S_{10} with the minimum total value of the preference functions $\gamma_{ij}(S_i, R_{ij}), i = 1, \dots, 10; j = 1, \dots 10$, which reflect the time and material costs of the transition from S_i to S_j. Numerical values of preference functions are indicated on the arcs of the graph in conventional units.

To simplify and systematize the compilation of Bellman functions, will number the vertices of Si so that the arc leaves the vertex with a smaller number. In this case we consistently find the fi functions for each vertex of the oriented graph from the Bellman functional equation

$$f_i = \min_j \{S_{ij} + f_j\}.$$

$$f_1 = 0, f_2 = \min\{S_{21} + f_1\} = \min\{3 + 0\} = 3, \quad f_3 = \min\{S_{31} + f_1\} = \min\{4 + 0\} = 4,$$

$$f_4 = \min\{S_{41} + f_1\} = \min\{2 + 0\} = 2, \quad f_5 = \min\begin{Bmatrix} S_{54} + f_4 \\ S_{53} + f_3 \\ S_{52} + f_2 \end{Bmatrix} = \min\begin{Bmatrix} 3 + 2 \\ 6 + 4 \\ 3 + 3 \end{Bmatrix} = 5,$$

$$f_6 = \min\begin{Bmatrix} S_{64} + f_4 \\ S_{65} + f_5 \end{Bmatrix} = \min\begin{Bmatrix} 1+2 \\ 1+5 \end{Bmatrix} = 2,\quad f_7 = \min\begin{Bmatrix} S_{76} + f_6 \\ S_{75} + f_5 \end{Bmatrix} = \min\begin{Bmatrix} 6+3 \\ 8+5 \end{Bmatrix} = 9,$$

$$f_8 = \min\{S_{86} + f_6\} = \min\{12+3\} = 15,\ f_9 = \min\begin{Bmatrix} S_{95} + f_5 \\ S_{98} + f_8 \end{Bmatrix} = \min\begin{Bmatrix} 7+5 \\ 6+15 \end{Bmatrix} = 12,$$

$$f_{10} = \min\begin{Bmatrix} S_{10,7} + f_7 \\ S_{10,9} + f_9 \\ S_{10,8} + f_8 \end{Bmatrix} = \min\begin{Bmatrix} 14+9 \\ 3+12 \\ 11+5 \end{Bmatrix} = 15.$$

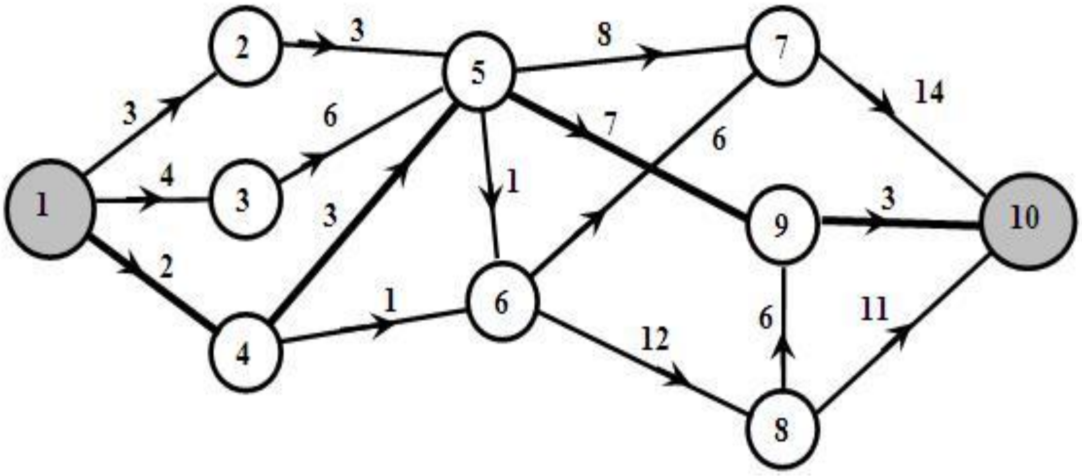

Figure 4. Fragment of a fuzzy situational network

The minimum selected amount of 3+12=15 corresponds to the vertex S_9.

$$f_9 = \min\begin{Bmatrix} S_{95} + f_5 \\ S_{98} + f_6 \end{Bmatrix} = \min\begin{Bmatrix} 7+5 \\ 6+15 \end{Bmatrix} = 12.$$

When calculating f_9, the vertex S_5 selected. Continuing in the same way, we get the shortest path from vertex S_1 to vertex $S_{10}(S_1, S_4, S_9, S_9, S_{10})$. In Fig.4 arcs of the optimal trajectory shown in bold lines.

Conclusion

The article proposes to use the mathematical apparatus of the theory of queuing systems for the analysis of passenger traffic on urban transport. As an example, a graph of states for fixed-route taxis is constructed and ratios are obtained for evaluating the main indicators of the quality of their work. In the conditions of frequent changes in road situations and uncertainty of the conditions for obtaining information about the current situation, it is proposed to carry out traffic management using intelligent decision-making support tools. In this regard, it is advisable to use an approach based on fuzzy situational management. For this purpose, the article proposes an algorithm for fuzzy situational management, which is the basis of intelligent IDSS. For an optimal transition from the current situation to a situation that meets the new operating conditions, in the sense of the selected criterion, it is proposed to use the dynamic programming method.

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