Modeling traffic streams on a road network section

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Abstract. The paper considers the issues of modeling traffic flows. Statistical data on the number of vehicles accumulating in front of the stop line for red lights are collected and analyzed, thereby determining the length of the queue of the traffic stream. The degree of influence of the driver’s reaction time on determining the average speed of the traffic stream on the road network of the city of Belgorod is considered. A fuzzy inference model based on the main parameters of the traffic stream is developed. A rule base is formulated that enables one to determine the average speed of traffic stream depending on the parameters of the traffic stream. The established dependence can be used when programming the controller or hardware implementation of the corresponding fuzzy control algorithm in the form of a decision table.

1. Introduction
A rapid growth of the automobile park leads to many problems, one of which is a decrease in traffic capacity. The movement of cars in the city of Belgorod is allowed throughout the road network (RN), except for several sections of RN located in the center and region of Kharkov Mountain.

The permitted maximum speed on RN is 60 km/h, in some places it is reduced to 40 km/h (Fig. 1).

Figure 1. Diagram of traffic speed modes in the territory of the city of Belgorod.
One of the main reasons for the decrease in traffic capacity is a decrease in traffic speed.

2. Main part
To improve the efficiency of traffic, it is necessary to optimize the speed limit (affecting the speed limit of vehicles in order to increase the traffic capacity of RN, increase the average speed, reduce travel time and improve traffic safety).

Reducing the congestion of the road network of a municipality is possible by changing the parameters of the existing transport network, which in turn causes a redistribution of traffic streams along the street network and changes traffic parameters [1, 3].

The following factors affect the distribution of traffic streams on a road network:
- change in external transport links;
- permission or prohibition of parking cars in the transport network of the city;
- introduction new elements of the transport network;
- commissioning of new centers of generation and attraction of transport;
- temporary closure or liquidation of any element of the transport system [2].

To assess the effectiveness of certain activities and their impact on the transport network, the following modeling methods are used and described below.

In many models with numerous advantages, there are significant disadvantages that do not fully take into account the main characteristics of the traffic stream. Thus, this gives an unfinished character in the modeling of the traffic stream.

3. Methodology
In this study, the fuzzy sets theory is applied. When managing technical systems, fuzzy modeling makes it possible to obtain the most adequate results in relation to results that are based on the use of control algorithms and traditional analytical models. In this regard, the use of mathematical tools to provide fuzzy initial information makes it possible to build models that most adequately reflect the many aspects of uncertainty that are constantly present in a real environment [6-8].

There is a number of stages in the development and application of a fuzzy inference system for the implementation of which it is necessary to fulfill basic provisions of fuzzy logic [10].

After conducting on-site examinations of some sections of the city’s RNs with a low traffic capacity at rush hour, it was decided to consider the effectiveness of RN functioning, namely, determining the speed mode depending on the queue of vehicles that accumulate in front of a traffic light for a prohibitory signal.

The studies adopted three input linguistic variables for a fuzzy model for determining the speed of vehicles that form the input vector $\beta = [\beta_1, \beta_2, \beta_3]$, and one output linguistic variable $\beta_4$,

where $\beta_1$ – transport stream queue length;
$\beta_2$ – rate of change of the queue length, accumulating on the prohibitory signal of traffic light regulation;
$\beta_3$ – driver’s reaction time;
$\beta_4$ – average traffic speed.

To describe each variable, membership functions are introduced that are uniformly distributed over the entire range of changes.

For $\beta_1$, the values from the statistical data are determined:
- VS (Very Small) – [0; 0; 15; 30];
- S (Small) – [15; 30; 45];
- M (Medium) – [30; 45; 60];
- B (Big) – [45; 60; 75];
- VB (Very Big) - [60; 75; 90; 90].

Figure 2 shows membership functions for linguistic variable $\beta_1$ ‘Quantity Length of the transport stream queue’. Data on the number of vehicles were collected as a result of an experiment that was conducted during the year.
Figure 2. Membership functions for linguistic variable $\beta_1$  
‘Length of the traffic stream queue’

Thus, term values and membership functions are defined for each variable. Next, the membership functions of term values for each of the variables of the fuzzy inference system are determined using the Matlab editor [9]. For the input variable, Figure 3 shows the graphical interface of the membership function editor.

Figure 3. Graphical interface of membership function editor for input variable  
‘Length of the traffic stream queue’

Membership functions are constructed similarly for the remaining variables. In our work, we compiled 62 rules of fuzzy products to determine the average speed of a traffic stream. The data were obtained from the measurement results and available data on the reaction time of drivers [6].

The following are five typical rules for fuzzy inference as an example:

1) IF $\beta_1 = S$ AND $\beta_2 = S$ AND $\beta_3 = M$ THEN $\beta_4 = S$;
2) IF $\beta_1 = VS$ AND $\beta_2 = Z$ AND $\beta_3 = M$ THEN $\beta_4 = B$;
3) IF $\beta_1 = VB$ AND $\beta_2 = Z$ AND $\beta_3 = V$ THEN $\beta_4 = S$;
4) IF $\beta_1 = VS$ AND $\beta_2 = S$ AND $\beta_3 = M$ THEN $\beta_4 = M$;
5) IF $\beta_1 = V$ AND $\beta_2 = S$ AND $\beta_3 = V$ THEN $\beta_4 = VS$

The first rule can be interpreted in natural language as follows: if ‘Traffic stream queue length’ $\beta_1$ is ‘very small’ (S – Small) AND ‘Rate of change of the queue length that accumulates on the restrictive signal’ $\beta_2$ is ‘very small’ (S – Small) AND ‘Driver’s reaction time’ $\beta_3$ is ‘medium’ (M – Medium), THEN ‘Average speed of traffic stream’ $\beta_4$ is ‘small’ (S - Small).

The result of calculating the traffic stream average speed based on fuzzy inference is illustrated by the example: $\beta_1 = 20$ - queue length of the traffic stream; $\beta_2 = 4$ – this indicates that the rate of change in the length of the queue is of a different nature; $\beta_3 = 1.4$ – driver’s reaction time. As a result of the fuzzy inference process, we obtained that $\beta_4 = 63$ is the average speed of the traffic stream. The graphical interface of the rule viewer after the fuzzy inference procedure is performed as follows (Figure 4).
To analyze the developed fuzzy model for determining the average speed of traffic stream, visualization of the corresponding surface of the fuzzy inference will be necessary and useful (Figure 5) [4, 5, 10].

4. Summary

Thus, using the fuzzy inference system, it is possible to solve the problem in determining the average speed of traffic stream. Implementation of the resulting fuzzy inference model is presented in the Fuzzy Logic Toolbox of the Matlab environment. Also, the graphical interface of the rule viewer and the surface of fuzzy inference was analyzed to build a model for determining the average speed of the traffic stream in order to evaluate the performance and adequacy of the developed fuzzy inference model.

Therefore, the obtained dependence can serve as basis for the hardware implementation of the corresponding fuzzy control algorithm represented by the decision table and controller programming.

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