1. Introduction

Passenger traffic affects the functioning of human life in the modern world. Economic indicators, production and simply the standard of living of the population depend on the speed and quality of transportation. The main task of passenger transport is the timely movement of users from one point to another. It is important for passengers that during the hours when they need to go to work or from it, transport runs more often. The choice of the route number also depends on how much faster one or the other will cover the distance from the initial to the final station [1].

As for such a parameter as technical condition, it becomes less significant during rush hours. The main problem of people at such a time is to get to the last point of travel, even sacrificing comfort. Since there is an incorrect distribution of transport or its lack. All this happens because the passenger traffic data is not updated, the routes change dynamically and they are not adjusted to the modern needs of people. Passenger traffic estimation data can help the dispatcher in scheduling, improve transportation and passenger satisfaction during the trip. This would have a positive effect on the city’s transport infrastructure. Trip schedules could be adjusted and drawn up so that drivers, on the one hand, do not stand idle, and on the other, do not drive empty. The purpose of this work is to investigate the operation of urban route transport, analyze the criteria affecting the assessment of passenger traffic and build a fuzzy model for assessing passenger traffic. It is necessary to implement the developed mathematical model in the form of a software product for conducting experiments.

Today there are many works devoted to the assessment of passenger traffic. So in the work [2], a three-phase fuzzy inference system (FIS) was proposed, where it was proposed to compare social and demographic variables to the total number of trips.

These works show that the key condition for successfully predicting the future is the correct analysis of what already exists. The main task was to describe as accurately as possible the human choice, which is more consistent with fuzzy logic compared to clear mathematics [3, 4]. Fuzzy logic can be a logical way to reflect such areas.

The work [4] did not take into account the influence of weather, seasons and urban culture during the assessment studies. At the same time, due to different weather and seasons, the condition of people is very different [5], which can also affect the pleasure of riding. Also, the problem is not taken into account how many buses passengers can choose to the same place. Riding pleasure influences passengers’ decision to choose a line. This is also a direction for future research.

In [6], a model for predicting traffic volume based on fuzzy logic was presented, where the input variables were weeks and time of day, and the output was the predicted traffic volume. Regarding the criteria for the attractiveness of the route, in the work [7], the significance of factors influencing the choice of passengers was investigated. Their comparison was carried out by the field method using questionnaires, after which a rating was made of such factors as travel time, fare, waiting time, number of transfers, etc.

The paper [8] also uses a non-linear regression equation to obtain an indicator of the quality of passenger transportation.

Analysis of decision-making problems for assessing passenger traffic showed that to solve problems, it is necessary to use processing approaches in conditions of fuzzy information.

2. Methods

Estimation of passenger traffic consists of many factors intertwined with each other. After analyzing various methods for solving this problem and revising similar problems, it was decided to take fuzzy logic as a basis.

To estimate passenger traffic using fuzzy logic, it is necessary to select the parameters, indicate the range of values that the parameters can take, and select the membership functions. There are many membership functions. But for this problem, a sigmoid and generalized bell was singled out [9, 10]. They are non-linear and do not have sharp peaks.

According to the subject area, the main criteria were selected that affect the passenger traffic. A fuzzy model for calculating the degree of confidence in the attractiveness of passenger traffic is presented in the following form:

\[
L = \{V\}_{i=1}^{m} \cdot \{R\}_{i=1}^{10} \cdot \{W\}_{j=1}^{10},
\]

where \(V\) is a set of input linguistic variables; \(R\) is a set of production rules; \(W\) is a set of output linguistic variables.

The set of input variables \(V\) consists of linguistic variables:

\[
\beta_i, \text{ defined by tuple } \{\beta_i, T(\beta_i), X_i\}, \text{ where } \beta_i = \{\text{vehicle spacing}\} = \{IS, IM, IL\}, X_i = [0; 1].
\]

It describes how often vehicles enter routes and how large the gap between vehicles is. Name of terms IS is a little, IM is a middle, IL is a large. Membership functions for terms IS, IL are the sigmoid membership function, IM is a generalized bell.

\[
\beta_i, \text{ defined by tuple } \{\beta_2, T(\beta_2), X\}, \text{ where } \beta_2 = \{\text{technical condition of the vehicle}\} = \{CB, CM, CG, CE\}, X = [0; 100].
\]
The parameter will be measured as a percentage, and its range will reach from 0 to 100 %. Where values closer to 0 will indicate a worse condition than those closer to 100. Such a term as «very bad» was not introduced, since with such an unsatisfactory condition of the vehicle, it should not be released on the route at all. Name of terms CB is a bad, CM is a middle, CG is a good, CE is an excellent. Membership functions for terms CB, CE are the sigmoid membership function, CM, CG are the generalized bell.

- $\beta_1$ defined by tuple $<\beta_1, T(\beta_1), X>$, where $\beta_1 =$route length$, $T(\beta_1)=\{MS, MM, ML\}$, $X=[0; 50]$. The length of the route will be measured in the number of stops along the route. Its range is from 0 to 50. The shorter the distance for the passenger from the initial stop, where it got into the vehicle, to the final one, the less time it will spend on the road and the more attractive the route will be for it. Name of terms MS is a short, MM is a middle, ML is a long. Membership functions for terms MS, ML are the sigmoid membership function, MM is a generalized bell.

- $\beta_4$ defined by tuple $<\beta_4, T(\beta_4), X>$, where $\beta_4 =$times of day$, $T(\beta_4)=\{TF, TM, TD, TE, TN\}$, $X=[4; 23]$. Vehicles enter and leave routes at different times, but a range such as from 4:00 am to 11:00 am can be distinguished when they are active. Name of terms TF is an early morning, TM is a morning, TD is a day, TE is an evening, TN is a night. Membership functions for terms TF, TN are the sigmoid membership function, TM, TD are the generalized bell.

When forming the base of rules $\{R\}_{j=1}^{180} = \{R_1, R_2, ... , R_{180}\}$ each rule is represented in the form of fuzzy products [9]. The knowledge of experts is incorporated into the software product. In total, 180 rules were created that describe all possible combinations of terms of linguistic variables.

The fuzzy knowledge base of information about the «input – output» relationship contains linguistic rules, examples of which are presented below:

1. If $\beta_1 =$big AND $\beta_2 =$bad AND $\beta_3 =$long AND $\beta_4 =$early morning THEN $\omega_1 =$small.

2. If $\beta_1 =$average AND $\beta_2 =$average AND $\beta_3 =$average AND $\beta_4 =$night THEN $\omega_1 =$average.

3. If $\beta_1 =$small AND $\beta_2 =$excellent AND $\beta_3 =$short AND $\beta_4 =$day THEN $\omega_1 =$large.

The rules are set by experts on the basis of subjective preferences and are not random.

The attractiveness of the route is influenced by all input parameters: the interval between vehicles, technical condition of the vehicle, route length and time of day. Depending on them, the output variable will be formed, with the help of which it is possible to estimate the passenger traffic. The closer the value is to one, the more confidence the passenger will choose this route as it is the most attractive.

The linguistic variable $\omega_1$ is defined by a tuple $<\omega_1, T(\omega_1), X>$, where $\omega_1=$the degree of confidence in the attractiveness of the route$, $T(\omega_1)=\{PS, PM, PL\}$, $X=[0; 1]$. Name of terms PS is a little, PM is a middle, PL is a large. Membership functions for terms PS, PL are the sigmoid membership function, PM is a generalized bell.

3. Results

To conduct an experiment to determine the attractiveness of the route, 15 routes were selected. Among the routes tested were all possible combinations of the interval between vehicles, technical condition of the vehicle, route length and time of day.

All data was taken from the system with real routes of the city of Mariupol, Ukraine.

Let’s conduct an experiment to check the effectiveness of the implementation of the proposed decision support method for assessing passenger traffic for an ordinary user (dispatcher). The proposed mathematical model formed the basis of the software. The experimental prototype was implemented as a web interface for user convenience. Any route can be evaluated in the software and multiple routes can be compared.

The time spent by the dispatchers on the analysis was also noted, the speed of each dispatcher is individual. Each person has a different pace of work, and there are many factors that can affect the overall performance. The software realizes the analysis almost instantly, while the speed is almost unchanged. Naturally, the speed of the software is much faster than the speed of the dispatcher.

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4. Discussion

The developed experimental model of the passenger traffic assessment system allows the dispatcher to determine the attractiveness of routes. The system is designed to facilitate the dispatcher’s work to assess passenger traffic by determining the attractiveness of routes, which can be used to reassign transport during rush hours and congestion of routes.

The study confirms that the use of this method reduces the time for analyzing passenger traffic and allows for a more accurate assessment of the congestion of public transport. To date, in the city where the study was conducted, the schedule is not dynamically adjusted, the exception is critical situations. The use of the obtained results will allow the dispatcher to build a dynamic schedule at different times of the day using the system to assess the attractiveness of routes. This technique can be used to support decision-making for a dispatcher when adding new routes or changing existing ones in any city of Ukraine.

5. Conclusions

As part of this work, the main criteria were identified that affect the assessment of passenger traffic, namely: the interval between vehicles; technical condition of the vehicle; route length; Times of Day. A mathematical model for assessing passenger traffic was built. The mathematical model is presented in the form of a fuzzy model with four input linguistic variables of one output variable; the system contains one hundred and eighty production rules. The rules were built on the knowledge of subject matter experts. The developed mathematical model formed the basis for a test prototype of software for evaluating passenger traffic, presented in the
form of a web interface. The software is supposed to simplify the work of dispatchers.

The results obtained indicate that the system, based on the knowledge of experts, estimates the attractiveness of passenger traffic more accurately than an ordinary user (dispatcher). All this together will help improve passenger traffic in public transport, reduce negative impressions from its use and improve the city’s infrastructure.

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