Model of an automated decision-making support system by a municipality in public transport management

E D Berisheva and E G Krushel

1 Volgograd State Technical University, 28, Lenina ave, Volgograd, 400005, Russia
2 Kamyskin technological institute (branch) of Federal state budgetary educational establishment of higher education «Volgograd State Technical University», Kamyskin, 6a Lenin, st., 403874, Russia

E-mail: elenaberisheva@mail.ru

Abstract. The static optimization model of passenger’s transport structure of small town is described. The transport network was interpreted by an oriented graph, whose vertices correspond to stops, and the arcs – parts of highways between stops. The route of transport was supposed to be given. The passenger traffic on each arc at the current fee was considered to be known.

1. Introduction

The population of Kamyshin and its city district, located in the Volgograd region, is 110 thousand people, the number of city public transport routes is 19, of which 12 are the most intensive in terms of passenger traffic. The city administration, considering it expedient to revise the structure of vehicle management, attracted a group of employees of the Kamyshin Technological Institute (branch of the Volgograd Technical University) to develop approaches to solving the following problems: the key question: “what should be the degree of participation of the municipality in the management of not only municipal, but also private passenger transport vehicles”.

A prerequisite for the customer was full-scale survey of the city’s passenger traffic, the methodology and analysis of which are presented in works from the first to the ninth. When solving this problem, the requirements for the optimization criteria are determined by the need to find such a solution on the subject of optimization in order to provide a compromise between the partially conflicting interests of various social groups of citizens. This task affects the interests of passengers, owners of personal transport vehicles, municipal authorities, traffic management services.

The generally accepted approach is to involve experts who are provided with a traffic simulation model. But due to the inevitable influence of differences in the decision-making style of each expert, it is desirable to support the work of the expert group with estimates of decision indicators that do not depend on the individual strategy. The need to develop such solutions, which are depending only on objective external factors and the selected criteria, is especially relevant when solving new problems for which a group of experts does not have a sufficiently reliable knowledge base (This is the case for this problem).

2. Materials and methods

To solve the problem, a well-known approach to the objectification of the decision-making process was used, based on the use of optimization models. The obtained optimal results are presented to experts for making a final decision [1, 3, 4]. This approach allows experts to present the boundary values of the calculated indicators corresponding to the maximum use of all resources of the system of restrictions to achieve the extreme of the selected criterion. Of course, the final decisions made by experts will turn out to be more “sparing”, taking into account both the objective inaccuracy of the initial data and the presence of interest groups not taken into account in the optimization criterion. But
the benefit in quantifying indicators that are potentially achievable under a set of constraints is undeniable. An additional argument in favor of choosing an optimization approach is the possibility of studying the dependences of the criterion and technical and economic indicators on the parameters of the constraint system. For example, in the problem under consideration, such parameters relate to the variation in the degree of participation of the municipality in the management of private transport vehicles.

The scheme of using the optimization approach:
1. Develop a system of decision-making criteria, based on the characteristics of a specific task.
2. Justify the way of transition from a multi-criteria problem to optimization problems of a single criterion.
3. To form a system of restrictions that determine the permissible range of variation of the calculated indicators, as well as indirectly taking into account the requirements for the rest of the criteria not accepted as being optimized.
4. Select an algorithm and software environment for solving the optimization problem.
5. Carry out calculations with variable parameters of the criterion and the system of restrictions.

The optimization subject is as follows:
1. Obtain an estimate of the number of private vehicles on each route;
2. Calculate the expected toll on each route;
3. Estimate the amount of profit on each route to predict the amount of tax revenue from the owners of each route.

The solution to the problem may be different depending on which of the interested social groups will assess the quality of the transport service system and propose the main indicator that meets its interests. Accordingly, a list of the following quality indicators was developed as a function of the sought variables “S”:

1. Indicator \( Q_1(S) \): total hourly profit from vehicles operations of all routes (meets the interests of the municipality and the city as a whole, since it provides a high level of tax revenues to the city budget):
   \[
   Q_1(S) = \sum_{i \in w_a} \Pi_i(S),
   \]
   \( \Pi_i(S) \) is the profit from the operation of the i-th route, \( i \in w_a \).

2. Indicator \( Q_2(S) \): specific hourly profit of all private transport organizations per 1 vehicle / hour (meets the interests of owners of private vehicles):
   \[
   Q_2(S) = \frac{1}{\sum_{i \in w_a} n_i} \sum_{i \in w_a} n_i(S) \cdot \Pi_i(S),
   \]
   \( n_i(S) \) is the number of vehicles serving the i-th route, \( i \in w_a \).

3. Indicator \( Q_3(S) \): the value of the total (on all routes) number of vehicles / hour (in the interests of traffic management services):
   \[
   Q_3(S) = \sum_{i \in w_a} n_i(S).
   \]

4. Indicator \( Q_4(S) \): weighted average (by the number of vehicles / hour on routes) fare (meets the interests of passengers):
   \[
   Q_4(S) = \frac{1}{\sum_{i \in w_a} n_i(S)} \sum_{i \in w_a} n_i(S) \cdot u_i(S),
   \]
   \( u_i(S) \) is the fare set by the owner of the i-th route, \( i \in w_a \).

5. Indicator \( Q_5(S) \): the minimum value of the maximum (on all routes) fare (this option is in the interests of the route owners, since it is aimed at softening competition between routes):
   \[
   Q_5(S) = \max_{i \in w_a} \{u_i(S)\}.
   \]
Accordingly, the problem of determining the values of “S” of the desired variables corresponding to a compromise between the partially conflicting interests of various social groups is formulated as the problem of optimizing the vector of indicators Q(S): \( \{ Q(S) = [Q_1(S), \ldots, Q_5(S)]^T \} \).

The approach proposed for solving the vector optimization problem contains 2 stages. At stage “1”, 5 one-criterion problems are solved, in each 1-th of which, \( 1 = 1, \ldots, 5 \), the optimal values of the sought variables \( S^* \) and the corresponding optimal value \( Q_v(S^*) \) of the corresponding indicator \( Q_v(S) \) are calculated, chosen as criterion. The values of the remaining indicators \( Q_m \), \( m = 1, \ldots, 5 \), \( m \neq v \), will generally have values that not only differ from optimal, but (possibly) will turn out to be unacceptable for other social groups. Criteria \( Q_1(S) \), \( Q_5(S) \) are to be maximized, the remaining criteria are to be minimized.

Stage “2” solves the problem of finding a compromise solution using two approaches. The first is based on scalarization of the vector \( Q(S) \), which is carried out in one of the following ways:

- finding a solution that delivers a minimum to the weighted average of the normalized deviations of indicators from their optimal values:

\[
\bar{Q}(S) = \sum_{v=1}^{5} a_v \frac{|Q_v(S^*) - Q_v(S^*)|}{\max(Q_v(S^*); Q_v(S^*))} 
\]  

(6)

The weights \( a_v \), of each of the components are calculated based on the number of citizens interested in the corresponding criterion;

- using the principle of Chebyshev alignment, which minimizes a single border “z” of normalized deviations of indicators from optimal values:

\[
a_v \frac{|Q_v(S^*) - Q_v(S^*)|}{\max(Q_v(S^*); Q_v(S^*))} \leq z \forall v = 1, \ldots, 5
\]  

(7)

Calculations for trade-off criteria (1), (2) must be performed for both different and equal values of the weight coefficients \( a_v \). Since the indices \( Q_v \), \( v = 1, \ldots, 5 \), do not completely contradict each other, one could expect that the solutions will not strongly depend on the choice of the weights \( a_v \), which was confirmed in the calculations.

The second approach is to optimize the \( Q_1(S) \) indicator, and to take into account the interests of individual groups of citizens, various ways of participation of the municipality in the management of private transport organizations are envisaged.

This paper describes examples of using the developed mathematical models to improve the efficiency of the transport system of Kamyshin, which has 19 routes and 78 bus stops. Characteristics of the scale of optimization problems: the number of sought variables is 200, the number of equality constraints is 100, and the number of inequality constraints is 400.

The above analysis showed that within the framework of a two-tier structure for managing private public transport, it will not be possible to provide a compromise between the interests of various social groups interested in the operation of the transport system.

Two variants of scalarization were tested: Chebyshev alignment with criterion (2), with different and equal weights of the equalized indicators and convolution of deviations of indicators from optimal values with different and equal weight coefficients, criterion (1).

In all scalarization options, the results were close and acceptable, but in all cases the choice of the final option remains with the team of experts.

A compromise between the partially conflicting interests of social groups in the management of the transport system can be ensured not only by scalarization of the vector criterion, but also by supplementing the “mandatory” system of constraints in the problems of partial optimization of each of the criteria \( Q_1(S), \ldots, Q_5(S) \) by “optional” restrictions from block 2 (chapter 3). Such restrictions are used to simulate various options for a municipality to participate in the management of a private transport system.

The dependences of each of the criteria on the parameters characterizing the intensity of these
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3. Conclusion
Based on the calculation results, the following recommendations were sent to the city municipality:

1. A two-tier structure for managing private public transport (the upper level is the owner or headman of the route, the lower level is a separate private vehicle) is ineffective, since within this structure it will not be possible to provide a compromise between the interests of various social groups interested in the operation of the transport system. It is advisable to introduce a third, upper level of the structure, which will be external in relation to private transport organizations (the level of municipal government). The functions of this level are ensuring a balance between partially conflicting interests of various social groups interested in the operation of the transport system.

2. Based on the calculations performed, the following was established:
   - the number of private vehicles currently in use in the city can be reduced at least 2 times without compromising the quality of passenger service. At the same time, the profit of individual routes should grow by at least 20%, while reducing traffic tension on busy highways and improving the environmental situation around them.
   - for the conditions of a small compact city, it is advisable to establish a single fare for all routes.
   - currently accepted in the city the value of the fare is understated. With a planned change in the structure of public transport management (ways of uniting owners of private vehicles into enterprises serving a specific route), this fee does not provide self-sufficiency for a number of routes. The recommended increase in the fare is no more than 30% compared to the existing.

3. It is advisable to provide for the equalization of profits between routes to prevent an unreasonable increase in fares and to maintain the existing system of public transport routes.

On the basis of these recommendations, the municipality decided to create a municipal enterprise “Autocolumn (transport service) of the urban district - the city of Kamyshin”, the introduction of which made it possible to abandon the unprofitable option of transport services by the forces of the regional autocolumn.

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