Controlling Traffic Flows in Intelligent Transportation System

Alexander Galkin and Anton Sysoev

Abstract The approach to control traffic flows in intelligent transportation systems is proposed. The algorithm is based on optimization of the transportation system functioning criterion which is speed (or time) of movement. The system is represented as a graph. The control consists of changing the traffic flows rate on individual sections of the system (graph edges), for example, by regulating the operation of traffic lights, and changing the capacity of sections, for example, by using reverse lanes.

Keywords Intelligent transportation systems · Effectiveness criteria · Optimization · Control · Graphs

1 Introduction

Regional transportation systems have a significant impact on social and economic development of the region. Therefore, the issues of modernizing transportation systems are always relevant. The upgrade may involve powerful infrastructure changes [cf. 1]: construction of new roads, transport hubs, development of new modes of transport, etc. These activities require significant financial costs and a long time to implement them.

Effective control of existing transportation infrastructure is another area of development of transportation systems, and, as a rule, the cost of implementing such measures is much lower, since no significant infrastructure changes are required. The duration of their implementation is also shorter. But such events have a limited scale of positive effects.

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A. G. Kravets et al. (eds.), *Society 5.0: Cyberspace for Advanced Human-Centered Society*, Studies in Systems, Decision and Control 333,
https://doi.org/10.1007/978-3-030-63563-3_8

The relevance and possibilities of effective control of transportation systems have increased with the development of information and telecommunications technologies [2]. The intellectualization of transportation systems is developing all over the world [3], and various technologies are being used. But all of them are based on collecting information about the current state of transportation systems and forecasts of the future state [4]. This information may include [5]: geo-information data (road and road network diagram, transport nodes, terrain, buildings, traffic control equipment, traffic flow diagram), traffic flow characteristics (speed, flow rate, density), information about meteorological characteristics of the environment (relative humidity, air temperature, pressure, precipitation), and others. The distinctive features of each intelligent transportation system are the ways in which such data is collected, processed, and used in control decisions [6]. Almost all transportation systems use graph structures to describe the road scheme, which is a universal tool in this case allowing to solve optimization problems [7]. The vertices of the graph can describe the transport nodes corresponding to, for example, the intersection of roads. And the edges describe the roads themselves.

2 Controlling Traffic Flows

2.1 Graph-Structural Approach to Modelling of Transportation Systems

Each vertex of the graph can be compared with a vector value that describes its various characteristics, such as the presence/absence of a traffic light or its signal, the incoming traffic flow rate, capacity, the value of carbon dioxide emissions, etc. For each edge of the graph, we can also match its own vector value $e^{(i,j)} = [x_i; x_j] = \left(e_1^{(i,j)}, e_2^{(i,j)}, \ldots, e_m^{(i,j)}\right)$, appropriate, for example, for traffic capacity, traffic flow rate, etc. In general, these characteristics are not constant and can change over time. It is also assumed that some of these characteristics can be controlled. For example, by adjusting traffic lights, it is possible to change the capacity of nodes, and by switching reverse roads, it is possible to change the capacity of roads and, as a result, the flow rate of incoming traffic at transport nodes [cf. 8]. The most common graph-structural object, modelling the traffic flows, is the transportation network [9, 10]. The main tasks include the equilibrium distribution in the transportation network [11, 12] and the search for the maximum flow [13, 14]. Control in an intelligent transportation system consists of setting conditions that optimize certain characteristics [15] of the transportation system state. In this case, these characteristics act as optimality criteria. There are many types of optimality criteria [16]: traffic safety, environmental impact, etc. But one of the main things is the speed (time) of movement. One of the possible values that characterizes this criterion is

$$k(e^{(k)}) = \frac{\lambda(x^{(i)})}{\mu(e^{(k)})}, \tag{1}$$

where $\lambda(x^{(i)})$ is the flow rate entering the vertex i, which is the beginning of the edge k, and $\mu(e^{(k)})$ is the capacity of the edge k. If the value of this criterion is less than 1, the movement is free and the speed is limited by permission signs. The criterion for the entire transportation system can be defined as follows

$$K_1 = \min \sum_{k=1}^{m} c(e^{(k)}), \tag{2}$$

where

$$c(e^{(k)}) = \begin{cases} 1, \ k_1(e^{(k)}) > 1; \\ 0, \ k_1(e^{(k)}) \leq 1. \end{cases} \tag{3}$$

Thus, the optimal situation is one in which the flow rate of incoming traffic does not exceed their capacity on as many edges corresponding to roads as possible. Let us consider the problem of choosing optimal controls for a transportation system, defined as a graph, and characterized by criterion (2). Let the graph have two parameters for each vertex i: $x_1^{(i)}$ is the flow rate of the incoming streams and $x_2^{(i)}$ is the maximum capacity, and each edge also contains two parameters $e_1^{(i,j)}$: $e_1^{(i,j)}$ is the flow rate of the incoming streams and $e_2^{(i,j)}$ is the maximum capacity. Let us assume that different traffic light control modes can be used as control actions, which change $x_2^{(i)}$ and reverse road switching, which change $e_2^{(i,j)}$.

Parameters set for graph vertices and edges are related. Figure 1 shows possible variants of the transport node scheme.

For the option (a) in Fig. 1 the link has the following form

$$\alpha_1 e_1^{(i,i_{out1})} + \alpha_2 e_1^{(i,i_{out2})} + \cdots + \alpha_n e_1^{(i,i_{outn})} = \min(e_1^{(i_{in},i)}, x_2^{(i)}), \tag{4}$$

where α_1, α_2, …, α_n are weight coefficients that characterize the separation of traffic flows along different edges that exit from the same node.

For the option (b) in Fig. 1 the link has the following form

$$e_1^{(i,i_{out})} = \min(e_1^{(i_{in1},i)} + e_1^{(i_{in2},i)} + ... + e_1^{(i_{inm},i)}, x_2^{(i)}). \tag{5}$$

For the option (c) in Fig. 1 the link has the following form

$$\begin{aligned} &\alpha_1 e_1^{(i,i_{out1})} + \alpha_2 e_1^{(i,i_{out2})} + \cdots + \alpha_n e_1^{(i,i_{outn})} \\ &= \min(e_1^{(i_{in1},i)} + e_1^{(i_{in2},i)} + ... + e_1^{(i_{inm},i)}, x_2^{(i)}) \end{aligned}. \tag{6}$$

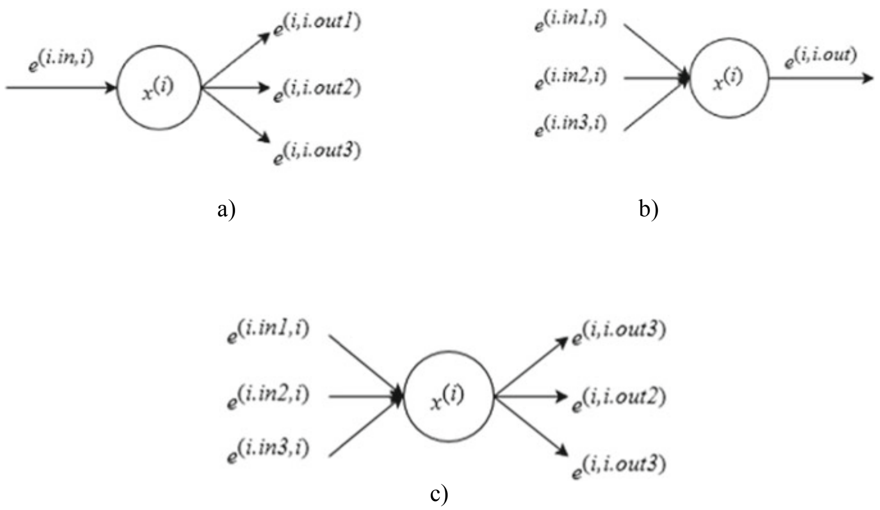


Fig. 1 Schemes of transport vertexes: **a** one input—several outputs, **b** several inputs—one output, **c** several inputs—several outputs

However, it should be kept in mind that for the option (a), if $e_1^{(i_{in},i)} > x_2^{(i)}$, changes the maximum capacity of the edge $e^{(i_{in},i)}$ as follows $e_2^{(i_{in},i)} = x_2^{(i)}$. For options (b) and (c): if $e_1^{(i_{in1},i)} + e_1^{(i_{in2},i)} + \cdots + e_1^{(i_{inm},i)} > x_2^{(i)}$, the maximum capacity of the edges changes $e^{(i_{in1},i)}$, $e^{(i_{in2},i)}$,..., $e^{(i_{inm},i)}$ as follows $e_2^{(i_{in1},i)} = \beta_1 x_2^{(i)}$, $e_2^{(i_{in2},i)} = \beta_2 x_2^{(i)}$,..., $e_2^{(i_{inm},i)} = \beta_m x_2^{(i)}$, where β_1, β_2, ..., β_m are weight coefficients that characterize the share of transport vertex capacity allocated to the corresponding incoming edge.

In order to account for the capacity of only edges, each vertex $x^{(i)}$ of the highway graph can be split into two vertexes—$x_{in}^{(i)}$ and $x_{out}^{(i)}$, at the same time setting a new edge $e^{(i_{in};i_{out})} = (x_{in}^{(i)}; x_{out}^{(i)})$. Then all incoming edges in the vertex $x^{(i)}$ will be included in $x_{in}^{(i)}$, while the outgoing ones will come from $x_{out}^{(i)}$. The vertex capacity of $x^{(i)}$, divided into two, will become the capacity of the edge $e^{(i_{in};i_{out})} = (x_{in}^{(i)}; x_{out}^{(i)})$. If there are vertices $x^{(j)}$, such that the graph has edges $e^{(i,j)}$ and $e^{(j,i)}$, then the edge $e^{(i_{out};i_{in})} = (x_{out}^{(i)}; x_{in}^{(i)})$ is also added.

2.2 *Approach to the Redistribution of Traffic Flows in Transportation System*

Control by adjusting the operating modes of traffic lights and switching reverse roads leads to changes in the capacity of individual graph edges. The total capacity of adjacent edges remains constant: $\sum_{j \in X} e_2^{(i,j)} + \sum_{j \in X} e_2^{(j,i)} = const$, where X is the vertex set of the graph.

Let us set the matrix of maximum edge capacities for a graph

$$E_2 = \begin{bmatrix} e_2^{(1,1)} & e_2^{(1,2)} & \dots & e_2^{(1,n)} \\ e_2^{(2,1)} & e_2^{(2,2)} & \dots & e_2^{(2,n)} \\ \dots & \dots & \dots & \dots \\ e_2^{(n,1)} & e_2^{(n,2)} & \dots & e_2^{(n,n)} \end{bmatrix} \tag{7}$$

and the matrix of traffic flow rate

$$E_1 = \begin{bmatrix} e_1^{(1,1)} & e_1^{(1,2)} & \dots & e_1^{(1,n)} \\ e_1^{(2,1)} & e_1^{(2,2)} & \dots & e_1^{(2,n)} \\ \dots & \dots & \dots & \dots \\ e_1^{(n,1)} & e_1^{(n,2)} & \dots & e_1^{(n,n)} \end{bmatrix}. \tag{8}$$

Let us compose the vector U of dimension n with elements presented as $\sum_{j \in X} e_1^{(j,i)} - \sum_{j \in X} e_2^{(i,j)}$ (difference between the sum of elements of the column i of the matrix (8) and the column i of the matrix (7)). The positive value of element means that the intensity of movement along the edges of the vertex i is higher than the capacity of the edges exiting it. The negative value indicates that there is a reserve of capacity of the edges emanating from the vertex i.

Next for each element of the resulting vector, we perform the following actions. If $U_i > 0$, we choose all the edges $e^{(i,j)}$, such as $U_j < 0$. Then the overall ability to increase the capacity of the node i will be $\sum_{j \in X_j} \left|U_j\right|$, where X_j is the set of vertices $x^{(j)}$, adjacent the vertex $x^{(i)}$.

For selected edges, according to the control capabilities, we increase the capacity as follows:

$$e_{2new}^{(i,j)} = e_2^{(i,j)} + \frac{\left|U_j\right|}{\sum_{j \in X_j} \left|U_j\right|} \min[|U_i|, \sum_{j \in X_j} \left|U_j\right|]. \tag{9}$$

This method is used to unload congested areas without loading them. The direct adjustment of the operating modes of the traffic light and reverse motion at the specified capacity capabilities is carried out according to the specialized algorithms [17–19]. The recalculation procedure (9) can also be repeated, if one considers the range of capacity not only of adjacent vertices, but also of vertices to which one can construct a route limited to a certain number of edges.

2.3 Numerical Example

Let us consider the example of traffic flow management in the transport network presented in Fig. 2.

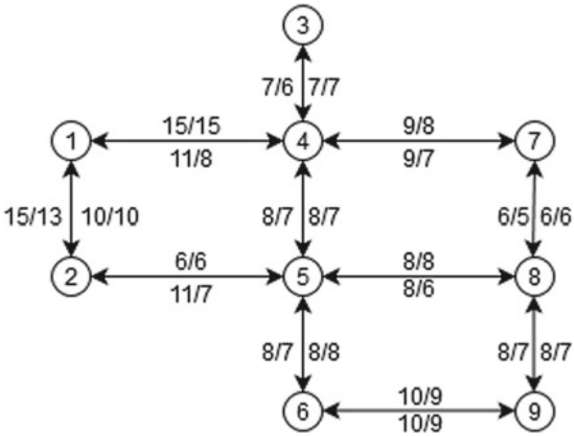


Fig. 2 Transportation network graph

The structure of the graph corresponds to the road sections in Lipetsk The lateral orientation of the edges in Fig. 1 corresponds to two opposite edges. Arrow signs stand for the the edge traffic flow respectively. The label above refers to an edge from left to right, the label at the bottom—from right to left. The label on the left refers to an edge with a direction from the top to the bottom, and the label on the right refers to the direction from the bottom to the top. In addition, the capacity of the vertices $x^{(2)} = [25;\ 30;\ 8;\ 32;\ 30;\ 15;\ 14;\ 20;\ 20]$ is specified. It corresponds to the total possibilities of the intersection determined by the given vertex when organizing movement in all possible directions. In this case, the redistribution of the total capacity of the vertices in all directions can be considered as a test to check its effectiveness. One of the most common ways to reach this is to adjust traffic lights.

To connect this section of roads to the entire urban transportation system is ensured by the formation of additional incoming traffic at vertices 1, 2, 7, 9 and the capacity of those leaving the transportation network at the same points. This can be taken into account by putting an extra vertex to the graph, as shown in Fig. 3.

In fact, the new vertex 0 is the analogue of the source and run-off in the classical transportation network. To implement the proposed flow control algorithm, a number of changes must be made to the graph: (1) each vertex having multiple inputs and multiple outputs from the same vertices (see option c) in Fig. 1), must be split into as many vertices as there are exits. The resulting vertices have one exit and contain all inputs except the input from the vertex where the exit is going. This is necessary to ensure that the flow from the input vertex is not redistributed to the vertex itself; (2) to transfer the capacity from vertices to edges, each vertex must be split into two. The first will include all edges. One exit with the capacity of the shared vertex will be directed to the second. The other one will have all the edges coming out. The example of this partition for the first vertex is shown in Fig. 4.

Vertex 1 was split into three: 1.0, 1.2 and 1.4. The second character in the number defines the vertex with which the output edge is connected. In turn, each of the three vertices obtained was split into two to transfer the capacity from the vertex to the

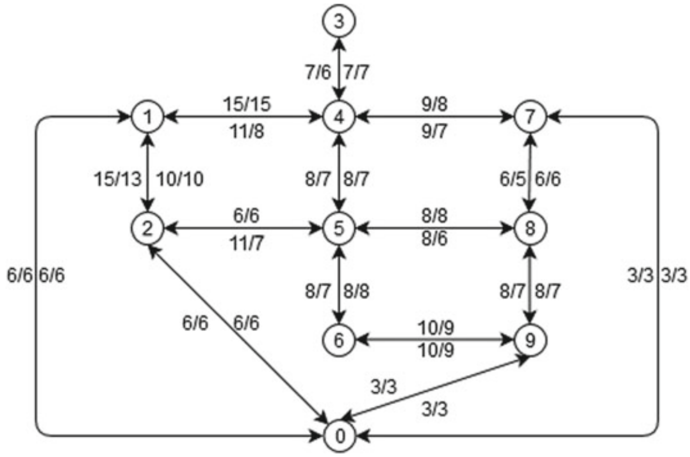
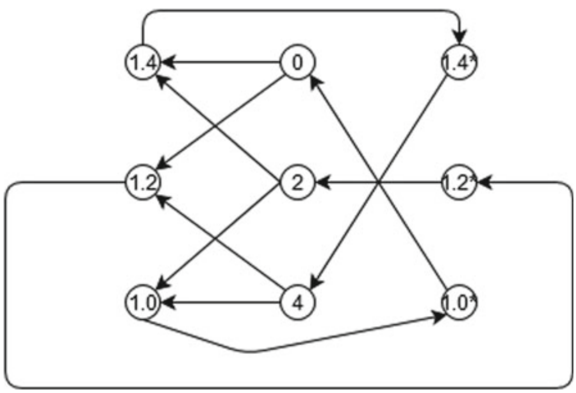


Fig. 3 Modified transportation network graph

Fig. 4 Partition of vertex 1



edges. The total capacity of the edges [1.0; 1.0*], [1.2; 1.2*] and [1.4; 1.4*] is equal to the capacity of vertex 1. The edge distribution is determined by the current traffic light setting. In the initial conditions of the task, let's assume that the capacity is proportional to the weight of the output edge among all exits, for example,

$$e_2^{(1.0,1.0*)} = x_2^{(1)} \cdot \frac{e_2^{(1,0)}}{e_2^{(1,0)} + e_2^{(1,2)} + e_2^{(1,4)}} = 25 \cdot \frac{6}{6+15+15} = 4,17.$$

Severed edge intensity values, e.g., [0; 1.2] and [0; 1.4], are determined by the weighting factors that characterize the division of the traffic across the different edges leaving the same vertex. Under the conditions of the problem, let the weights be proportional to the weight of the output edge among all exits, for example,

$$\begin{bmatrix}
0 & 0 & 3 & 3 & 0 & 0 & 0 & 0 & 3.75 & 2.25 & 0 & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & 4.167 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 10.417 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 0 & 10.417 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 7.5 & 0 & 7.5 & 0 & 0 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8.182 & 0 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 13.636 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8.182 & 0 & \\
6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
0 & 2.857 & 0 & 7.143 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
0 & 3.143 & 7.857 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 7 & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
\vdots & & & & & & & & & & & & & & \ddots
\end{bmatrix}$$

Fig. 5 Capacity matrix fragment

$$e_1^{(0,1.2)} = e_1^{(0,1)} \cdot \frac{e_2^{(1,2)}}{e_2^{(1,2)} + e_2^{(1,4)}} = 6 \cdot \frac{15}{15+15} = 3.$$

In the end, capacity and flow rate matrices are determined for a graph (Fig. 3) of size $[52 \times 52]$. Figures 5 and 6 show the fragments of the obtained matrices.

The value of the vector U is calculated from the obtained matrices as follows:

$$\begin{aligned} U = [&0.; 0.97619; -1.70238; -0.27381; -1.83333; -6.28571; \\ &-4.85714; 0.943182; -5.51136; 0.568182; 2.18182; -1.875; \\ &2.18182; 0.; -1.88661; 1.67443; 1.55385; 1.65833; -2.82947; \\ &-0.6; 0.685714; -0.771429; -4.13228; -1.00529; -3.07937; \\ &-2.78307; 0.407407; -1.85185; -0.0740741; 0.518519; 2.33333;]]. \text{ The} \\ &-1.33333; -1.33333; -3.; -0.833333; -0.7; -3.46667; 3.83333; \\ &-2.7;\ 5.86667; -0.272727; 0.974026; 0.298701; -1.5; \\ &0.428571; -0.928571; -1.01099; -1.7033; -6.28571; \\ &3.52448; -2.94872; 6.42424 \end{aligned}$$

value of the criterion obtained is $\sum_{k=1}^{52} c(e^{(k)}) = 18$.

Among the many positive elements selected are those whose capacity can be modified. These elements are [2.5; 4.3; 4.5; 4.7; 6.5; 8.7; 8.9]. So for the elements 2.5 and 8.7 there are no edges $e^{(2.5,j)}$ and $e^{(4.8,j)}$, such as $U_j < 0$, and their capacity cannot be increased. Among the remaining edges the edge i is selected, for which the maximum value is $\sum_{j \in X_j} \left| U_j \right| - U_i$, where X_j is the set of vertices $x^{(j)}$, adjacent the vertex $x^{(i)}$, with negative values of U_j. Such a vertex is 8.9. So we recalculate

$$\begin{bmatrix}
0 & 0 & 3 & 3 & 0 & 0 & 0 & 0 & 3.75 & 2.25 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 4.167 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 8.714 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 10.143 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 6.5 & 0 & 6.5 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8.182 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8.125 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8.182 & 0 \\
6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 2.857 & 0 & 7.143 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 2.286 & 5.714 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 7 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.625 & 4.375 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\vdots & & & & & & & & & & & & & & \ddots
\end{bmatrix}$$

Fig. 6 Traffic flow rate matrix fragment

the new edge capacity with formula (9):

$$e_{2new}^{(8.9,8.9*)} = e_2^{(8.9,8.9*)} + \frac{\left|U_j\right|}{\sum_{j\in X_j}\left|U_j\right|}\min[|U_{8.9}|, \sum_{j\in X_j}\left|U_j\right|].$$

$$= 7.272727 + 0.298701 = 7.571428$$

That is the edge capacity must be increased by 0.298701. Increase in capacity in the example presented can only be achieved by redistributing the total capacity of the vertex between its outgoing edges (traffic lights regulation). In this case, the limit on the value of the total capacity of the vertex should be respected. In our case $e_{2new}^{(8.5,8.5*)} + e_{2new}^{(8.7,8.7*)} + e_{2new}^{(8.9,8.9*)} = const$. The edge $e_2^{(8.5,8.5*)}$ has the capacity reserve of 0.772727.

As a result, the following capability modifications are made:

$$e_{2new}^{(8.9,8.9*)} = 7.272727 + 0.298701 = 7.571428,$$

$$e_{2new}^{(8.5,8.5*)} = 7.272727 - 0.298701 = 6.974026.$$

We get the value of the criterion $\sum_{k=1}^{52} c(e^{(k)}) = 17$. and repeat this procedure with new capacity and intensity matrices as long as the criterion is reduced. In the example given, the value of the criterion can be reduced to 14.

3 Conclusion

Thus, the traffic control algorithm in Intelligent Transportation Systems is presented in this chapter. The intelligent transportation system is expected to collect and analyze real-time traffic information. This information is used by the traffic control algorithm. The algorithm is based on optimization of the performance criterion of the transportation system—speed (time) of movement. In the above example, using the algorithm it is possible to reconfigure traffic lights modes in such a way that the total number of congestion sections decreases from 18 to 14. In case of optimizing not only current state of the system but also taking into account the future possible states the presented approach could be extended to time-dependent graphs described in [20].

Acknowledgements The study was carried out with a grant from the Russian Science Foundation (Project 18-71-10034).

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