Methods for determining the transport detectors’ placement on road network

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Abstract. The article discusses the methods’ development for determining the transport detectors location on the road network. In studying this problem, various approaches to collecting data on traffic flows are analyzed. The basic requirements for determining the number of data collection points and their location are formed. These requirements can be used in traffic monitoring systems. The proposed methods were tested using a model experiment on a test example. The simulation results showed the effectiveness of the considered methods.

Introduction
In modern intelligent transport systems (ITS), information support on the traffic flows and traffic conditions’ characteristics is of the utmost importance. Traffic intensity, density (traffic concentration) and speed provide primary information for the automated traffic control systems’ functioning, the choice of traffic control parameters in accordance with the real situation. Therefore, the detectors location choice is mainly determined by the needs of the automated traffic control systems’ maintenance. However, the functions of intelligent transport systems are constantly expanding and the traffic flows distribution in the network, route orientation, incident management become the mandatory tasks, and these tasks should be solved in real time [1, 2, 3]. All these tasks require the presence of correspondence matrices in the intelligent transport system functioning area. In this case, it is necessary not only to have information in the traffic lights installation zone, but also to control the traffic flows parameters on the road network as a whole. For this, it is necessary to ensure the optimal placement of recording traffic flows means in order to reduce the cost of the monitoring system, but without losing the necessary data. This data should guarantee the possibility of monitoring the most significant and probable routes. With all approaches to solving this problem, the general requirements are to ensure the assessment accuracy of the primary correspondence matrices and the availability of reliable information about the changes in the traffic load on the network sections [4, 5].

Methods for solving the transport detectors’ optimal placement problem
For the large dimension networks, it is impossible to fix traffic flows on all routes between the points of start and end of the trip, therefore, the detectors’ optimal placement problem is different and is not dictated only by the technological features of automated traffic control systems. The main target setting is to determine the minimum number of detectors and their installation locations while
providing sufficient information about the traffic flows distribution in the network. To achieve this goal, methods for determining the detectors’ location should meet the following requirements [6, 7, 8, 9]:

- in order to obtain the guaranteed volume and quality of information for the correspondence matrix, the detectors’ location should ensure registration of a given share of trips between any pair of the points of start and end of the trip. The purpose of this requirement is to establish a minimum number of detectors monitoring at least once all pairs of links in the correspondence matrix;
- the detectors should be located in areas with the maximum traffic load on the route connecting the points of start and end of the trip in the correspondence matrix;
- the detectors should be located in such a way as to ensure the traffic flow parameters’ registration on those sections of the network where as many routes as possible between the points of start and end of the trip intersect in the correspondence matrix;
- to ensure independence between the traffic concentration in the selected sections of the network, transport detectors should be located in such a way that there is no linear relationship between traffic intensity in the connected sections of the road network.

The technique for solving the detectors’ optimal placement problem is shown in Fig. 1. The algorithm includes creating a primary correspondence matrix, modeling traffic on the network in question, distributing traffic flows on the network for various conditions, placing the detectors in accordance with the above-made conditions and evaluating the received correspondence matrix.

Initially, for a given scenario, a correspondence strictly determined matrix should be created. Then, based on the transport demand specified by this matrix, the traffic flow distribution in the network is carried out [6, 10, 11, 12]. In accordance with the results of this procedure, micro-modeling of traffic is carried out.

Usually, the flows’ maximum intersection condition is the optimization goal, and the condition of independence of network sections is a limitation. The condition of maximum intersection is formulated as follows [6, 15]

$$\text{MAX} \sum_{i \in I} \sum_{k \in K} \hat{q}_k y_k,$$

under conditions

$$\sum_{a \in A} \delta_{ak} x_a \geq y_k, \ \forall i \in I, \forall k \in K$$

$$\sum_{a \in A} x_a = n,$$

$$x_a \in \{0,1\}, \ \forall a \in A\ x_a$$

$$y_k \in \{0,1\}, \ \forall k \in K$$

$$x_a = \begin{cases} 1 & \text{if the detector is located in the area a} \\ 0 & \text{otherwise} \end{cases}$$

$$\delta_{ai} = \begin{cases} 1 & \text{if a trip between a couple i matrices} \\ 0 & \text{otherwise} \end{cases}$$

where \(a\) – is the network section of the total set \(A\);
\(q\) – defines the network flow;
\(i\) – is the number of pairs in the correspondence matrix;
\(n\) – is the number of detectors.
To satisfy the rule of the network sections’ independence, it is necessary to solve the following problem:

\[
\min x_0 = \sum_{a \in A} x_a \\
\sum_{a \in A} \delta_{ai} x_a \geq 1, \forall i \in I \\
x_a \in \{0,1\}, \forall a \in A
\]  

\(4\)

In the process of modeling at the micro level, there will always be deviations from the original matrix of transport demand due to the fact that the modeling uses probabilistic approaches to determine the intervals between cars, the choice of driving routes in accordance with the load level or time of movement in different parts of the network. The more difficult the traffic conditions, the greater the magnitude of these deviations. Also, during the simulation, the data from transport detectors are recorded [16, 17].

Then, in accordance with the methods described above, sequential placement of the detectors is carried out. At the final stage of the algorithm, the deviations of transport demand are estimated for the primary and reconstructed correspondence matrix. The adequacy of the results is estimated by the value of the transport demand relative total deviation in the correspondence matrix:

\[
\varepsilon_{TD} = \frac{\left| \sum_{i} q_i - \sum_{i} q_i^p \right|}{\sum_{i} q_i^p},
\]

\(5\)

where \(\varepsilon_{TD}\) is the relative total deviation of transport demand;
"$q^e$" – is the estimated value of the volume of movement between the points of connections in the correspondence matrix;
$q$ – defines the actual value of traffic volume between the same points of connections;
$n$ – is the number of measurements.

The formulas were used to estimate the distribution of detectors in the simulation zone.

**Simulation results**

The configuration of the simulation zone is shown in Fig. 2. This zone has a complex scheme with interchanges at different levels with a significant difference in traffic load in different areas. The simulation results are shown in Table 1.

![Figure 2. Fragment of a modeling plot in the optimal detector placement methods’ study](image)

| Bond pair numbers | Intensity of movement between the bond pairs, vehicle / h | Total flow vehicle / h |
|-------------------|--------------------------------------------------------|-----------------------|
|                   | 1           | 2             | 3        | 4          | 5          |                      |
| 1                 | -           | 140/126       | 1790/1850| 2580/2442  | 175/163    | 4685/4581            |
| 2                 | 520/620     | -             | 50/22    | 10/27      | 40/70      | 620/739              |
| 3                 | 1980/1989   | 55/63         | -        | 10/4       | 20/25      | 2065/2081            |
| 4                 | 2180/2539   | 28/43         | 11/10    | -          | 650/391    | 2869/2983            |
| 5                 | 175/212     | 250/290       | 225/350  | 200/248    | -          | 850/1100             |
| Total flow vehicle / h | 4855/5360 | 473/522       | 2076/2232| 2800/2721  | 885/649    | 11089/11484          |

Table 1. Comparative data of the correspondence matrix. In the numerator, the given data, in the denominator, the data obtained as a result of monitoring. The numbers of pairs of bonds correspond to the numbers in Figure 2.

For complete traffic control in this modeling zone, it is necessary to create 20 points for monitoring traffic flows. Based on the above-described methods and the computational algorithm, the number of monitoring points can be reduced to 5-7, depending on the priority in using any of the four requirements given in the article. Table 1 shows the results of the correspondence matrix restoration at the request of the correspondence matrix maximum coverage.

The data in Table 1 show that the modeling zone under consideration is characterized by a significant difference in transport load in different parts of the network. This greatly complicates the task of determining the optimal distribution of monitoring points. But even for these difficult
conditions, satisfactory results were obtained. The relative total deviation of transport demand in the correspondence matrix is 0.118 with an allowable deviation of 0.15, which indicates the reliability of the results.

Summary
Thus, the data obtained show that the use of recommended methods for determining the number of detectors and their locations can reduce their number while providing the reliable information for determining the correspondence matrices. In further studies, it is necessary to study the adequacy of these methods in relation to large-dimensional networks.

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