Special aspects of the use of "floating" cars information to estimate the quality of road traffic in real time

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Abstract. The article provides a rationale for the transition from the existing estimation methods of traffic conditions, focused on a single car-laboratory, to total "floating" cars methods of estimation at the network level. The paper presents the results of cluster and dispersion analyzes of experimental data. Based on these results it was concluded that a reliable estimation of the proportion of simultaneously stopped cars can be carried out when measuring traffic parameters with different time discreteness in the range from 1 to 180 seconds.

Introduction
The parameters of two-fluid models of the kinetic theory of traffic flow fully meet the requirements for parameters in the operational estimation of traffic conditions: they are informative with regard to the changes in traffic conditions and methods of traffic management; registration conditions for these parameters, especially the proportion of simultaneously stopped cars in the network \( f_s \), are simple; the existence of the obtained dependencies \([1, 2, 6, 8]\) provides the minimum delay in the process of accepting management actions.

However, to apply these parameters when solving practical tasks of traffic management, it is necessary to eliminate contradictions between existing methods of information collection and processing using “floating cars” and new functional requirements for using such information in intelligent transport systems \([3, 4, 7, 9]\). The main task is to make the transition from the existing estimation methods of traffic conditions, focused on the local points, to total "floating" cars methods of estimation at the network level.

Goals, Tasks, Methods of Study
To accomplish this task, experimental studies were conducted on the road network of the city of Rostov-on-Don. The experiment was conducted in the central business district of Rostov-on-Don. This area of the city is characterized by a high density of the road network of about 4.5 km/km\(^2\) (including 1.8 km/km\(^2\) of main roads), the operation of main roads almost at the level of traffic capacity all through the day, and average traffic speed from 14 to 24 km/h. Such complex traffic conditions are the most preferable for the study of estimation methods for the traffic quality on the network.

The main objective of the experiment was to determine the measurement discreteness of two-fluid models parameters of the kinetic theory of traffic flow; to determine the required number of "floating" cars constantly running in a given area, the duration of the monitoring period for making a reliable estimation of traffic conditions. In accordance with this goal, the implementation of the experiment
took place by gradually increasing the number of simultaneously moving vehicles (1, 2, 3, ... n), which were used to record the characteristics of traffic flows and the duration of monitoring.

In the course of experimental research, all floating cars started and completed their movement at the same time. The experiment was carried out in two main scenarios: planned and random. In the first scenario, the floating cars started to move from different points of the area and during the whole experiment they moved along fixed routes. These routes were determined before the start of the experiment based on the conditions of uniform coverage of the entire research area, the constant existence of vehicles on the highway network, and control over traffic conditions on the most difficult sections. Floating cars were not allowed to deviate from these routes. Thus, continuous monitoring of traffic flow characteristics throughout the study area was achieved.

The essence of the second scenario was to adapt the "floating" cars to the stochastic nature of the road traffic. The only limitation for the experimental "floating" cars was not to leave the area under the study. The task of this floating "car" driver was to select any vehicle in front of him and follow it until it leaves the area or ended the trip. In this case, the "floating" car chooses any other car as a leader. Therefore, it is possible to compare the results of various strategies for floating cars use. In the course of research, synchronous registration of the traffic parameters of all experimental vehicles was carried out.

One of the most preferable parameters in the "floating" cars informational survey is the proportion of simultaneously stopped cars in the network. On the one hand, to obtain data in this parameter determining, it is enough to organize information exchange between the traffic management system and the car in the "yes" - "no" mode. On the other hand, the results of earlier studies showed that this parameter is related to the characteristics of traffic flows and criteria for estimating the quality of traffic management [5, 10, 11].

The discreteness determination of the survey of "floating" cars drivers to estimate the proportion of simultaneously stopped cars in the network was carried out in the range from 1 to 600 s. One of the variants of the obtained results is presented in table. 1. The change in the $f_s$ parameter depending on the measurement discreteness for a set of different observations is shown in Figure 1.

![Figure 1. Influence of measurement discreteness on the $f_s$ value estimate](image)

For an initial estimation of the degree of divergence of $f_s$ values and grouping the results of measurements of this parameter with different discreteness, the cluster analysis was performed. Figure 2 show the results of cluster analysis.

At the next stage of research, it is necessary to check at what measurement discreteness the differences between the estimation of $f_s$ in every second mode and the estimation of $f_s$ at a given
discreteness level become significant. This task can be interpreted as one of the typical tasks of dispersion analysis, when it is necessary to determine whether the influence of various factors or their interactions on the change of process parameters is significant against the background of random deviations. Since the factors in the dispersion analysis have a qualitative character, it is possible to study the influence on the process of factors located at different levels: a set of floating cars, methods for assigning and choosing the routes of their movement, methods for parameters measurement.

Data for dispersion analysis are presented in the form of \( n \ p \)-dimensional values of the parameter. The table below shows the statistical characteristics of these values at different measurement discreteness.

**Table 1. Statistical characteristics of \( f_s \) at different measurement discreteness**

| Measurement discreteness | Variation range of \( f_s \) | Average value \( f_s \) | Confidence 95% interval for average value \( f_s \) | Variation coefficient, [%] |
|---------------------------|------------------------------|-------------------------|---------------------------------|--------------------------|
|                           | min | max  |                  | min | max |                                    |                         |
| 1                         | 0.0 | 0.66 | 0.2698           | 0.2654 | 0.2742 | 6.63                               |                         |
| 2                         | 0.0 | 0.66 | 0.2693           | 0.2631 | 0.2755 | 6.65                               |                         |
| 5                         | 0.0 | 0.66 | 0.2682           | 0.2585 | 0.2780 | 6.56                               |                         |
| 10                        | 0.0 | 0.66 | 0.2672           | 0.2535 | 0.2808 | 6.47                               |                         |
| 20                        | 0.0 | 0.583| 0.2699           | 0.2517 | 0.2881 | 5.56                               |                         |
| 30                        | 0.0 | 0.583| 0.2604           | 0.2374 | 0.2834 | 6.22                               |                         |
| 60                        | 0.0 | 0.5  | 0.2708           | 0.2402 | 0.3014 | 5.17                               |                         |
| 120                       | 0.0 | 0.5  | 0.2639           | 0.2191 | 0.3087 | 5.46                               |                         |
| 180                       | 0.0 | 0.5  | 0.2375           | 0.1791 | 0.2959 | 6.57                               |                         |
| 300                       | 0.166 | 0.417| 0.3264           | 0.2736 | 0.3791 | 2.11                               |                         |
| 600                       | 0.166 | 0.417| 0.3194           | 0.2172 | 0.4217 | 2.97                               |                         |

Equation (1): \( Y_j = \begin{bmatrix} y_{1j} \\ M \\ y_{pj} \end{bmatrix} \) (\( j = 1,2,\ldots,n \))

**Figure 2.** Formation of homogeneous clusters for measuring the proportion of simultaneously stopped cars in the network with different discreteness.

Data for dispersion analysis are presented in the form of \( n \ p \)-dimensional values of the parameter.
under study. As assumptions, it is assumed that each measurement vector \( Y_j \) belongs to a \( p \)-dimensional normal sample and all these observation vectors \( Y_j \) are mutually independent.

\[
M = (\mu_1, \mu_2, \ldots, \mu_n) \quad (2)
\]

\[
M' = X B 
\quad (3)
\]

The following relationships should also be met:

Matrix \( B \) is formed from unknown parameters, and \( X \) is the matrix of the experiment plan.

Based on the set of observation vectors \( Y_p \), a matrix of observations is formed and an equation of a multidimensional model is obtained taking into account the random components of the measured values

\[
Y' = X B + E
\quad (4)
\]

The null hypothesis lies in the fact that the average values of the various measurements are equal

\[
H_0 : K B = O 
\quad (5)
\]

An alternative hypothesis is expressed as follows

\[
H_1 : K B \neq 0 
\quad (6)
\]

where \( K \) is a given matrix.

To test the null hypothesis, the \( F \)-criterion is used

\[
F = \frac{1}{n-r} \frac{[K \left(YX'X^{-1}K'\right)^{-1} \cdot K \left(X' \cdot X^{-1} \cdot X'\right)]}{n-r} \quad (7)
\]

The null hypothesis is discarded in the case when the actual value of the \( F \)-criterion will be greater than the tabular one at the corresponding significance level and the number of freedom degrees

\[
F > F_{s,n-r,\alpha}
\]

Using the method of dispersion analysis, we will make a significance estimation of the influence of measurements discreteness on the estimation of the proportion of simultaneously stopped cars in the network. The statistical characteristics describing the data array used in the analysis are shown in Figure 3.

![Figure 3. The main statistical characteristics of the source data used in the dispersion analysis](image)

Figure 3. The main statistical characteristics of the source data used in the dispersion analysis
Since we define the real values of $f_s$ obtained with the measurements discreteness $\Delta t=1\ s$, we perform the first dispersion analysis for pairwise comparisons of observations with $\Delta t=1\ s$ and any other discreteness. The table value of the criterion for accepting the null hypothesis is

$$F_{1, 10; 0,05} = 4.96.$$ 

Considering the calculated values of $F$ for different measurement discreteness, it can be concluded that before the measurement discreteness of 180 s there is no significant effect of $\Delta t$ on the values estimation of the proportion of simultaneously stopped cars.

Summary
The conclusions that can be drawn from the results of dispersion analysis of the observations cumulative result with different measurement discreteness $f_s$ are that it is possible to estimate the proportion of simultaneously stopped cars when measuring traffic parameters with different discreteness $\Delta t$ when changing $\Delta t$ in the range from 1 to 180 seconds.

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