



## IMPLEMENTATION OF EXPERIMENTAL RESEARCH IN ROAD TRAFFIC: THEORY AND PRACTICE

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**Abstract.** The article describes the questions of experimental researches in road traffic and possible alternatives for the implementation of the experiment. Evolutionary planning is suggested as the basic planning of the experiment. Some results are given from the research of the main parameter – volume of traffic flows. Satisfactory management is far from optimal management and huge reserves are still available here. The problems of collecting data on the parameters of traffic flow have been studied by many researchers. In this article authors also tried in a certain way to enlighten a number of questions related to the implementation and planning of experimental researches in the field of road traffic.

**Keywords:** parameters of traffic flow, methods for the implementation of the experiment, evolutionary experiment, planning of the experiment.

### 1. Introduction

Traffic flow, as a physical process, has certain characteristics and is subject to certain regularities. In this relation it could be compared to the other physical processes, for example, to the flow of a liquid. However, traffic flow has its specific features determined by the fact that each of its elements is controlled by the human. Therefore, the interaction of elements of traffic flow is described not only by the physical laws but also by the elements of psychophysiology, psychology, ethnography, etc. All this makes the study and the management of traffic flow extremely difficult.

Traffic flow is a random process characterised by random variables. A study of random processes requires extensive statistical material, profound mathematical knowledge and performance assurance, but, unfortunately, we still lack much of this.

Therefore, random variables – characteristics of traffic flow – are studied as deterministic, to be more precise, as point estimates of random variables. Also it should be kept in mind that all of them are random. Such an approach requires a lot of assumptions, has large errors but it is methodologically reasonable and gives a sufficient understanding of the characteristics of traffic flow and their inter-dependencies. This understanding is enough to satisfactorily manage the road traffic. The management of road traffic requires knowledge about many characteristics of traffic in conflict objects. In this article authors also tried

in a certain way to enlighten a number of questions related to the implementation and planning of experimental researches in the field of road traffic (Brilon 2002; Врубель 1996).

### 2. Methods for the planning of experiment

When studying processes related to road traffic a passive method of research is mainly used. It is based on the data of the system Driver – Vehicle – Road – Environment (DVRE) under certain concrete and foreknown conditions. A specific feature of implementing a passive experiment is that the factors, influencing road traffic, and the output parameters are recorded without introducing any changes into the process of road traffic (the process is not controlled by the experimenter). Methodology of a passive experiment is based on the hypothesis that it is possible at any degree of accuracy to define all the variables of the DVRE system on the required level. By varying the factors one after another but leaving all other factors fixed, it is possible to identify the regularities which join the factors of the given system (significant factors). It seems that the methodology of such experiment has an essential deficiency – it does not take into consideration that the functioning conditions of the DVRE system are undefined, has an accidental character and, when varying with only one factor the others can also change in the process of implementing the experiment, i.e. the interaction between the

factors (when the value of one factor depends on the level on which the other are) is ignored.

Thus, for the research of road traffic processes the methods of active (multi-factorial) experiment must be used. Planning of such experiment requires an active intervention of the experimenter into the process of road traffic and gives a possibility to choose for every trial the factors of the greatest interest for the purpose of research.

However, irrespective of the whole evident advantages of the active multi-factorial experiment, its wide use for the research of traffic-pedestrian flows is rather difficult. Accidental changes of factors, attributed to initial ones, are analogical to noise and, therefore, in order to make out a valid signal it is necessary to set large intervals for the variation of manageable factors. It is obvious that in this case the negative results are possible which could cause a disturbance of a normal functioning of road traffic (delays, accidents, reduced speed, etc.) (Kapski *et al.* 2007; Viteikienė, Zavadskas 2007). The manageable factors must be strictly recorded on a certain level and this, as we know, is impossible to be achieved in road traffic. The process becomes irreversible.

Therefore, the active experiment as such cannot be used for studying the processes of road traffic. It is necessary in a certain way to take into consideration the specific features of the implementation of the active experiment and the possibilities to study characteristics of road traffic which could be treated as partly managed if compared to the other factors. Thus, the method of the black box or evolutionary planning of the experiment, or transfer functions is more prospective.

The basis of evolutionary scheme for implementing the experiment lies in the classification of factors characterizing the system according to their role in the management process (Иванов 1966) (Fig. 1).

The factors are grouped as follows: managed factors  $x_1, x_2, x_3, \dots, x_l$  determine the control effects. They allow a purposeful variation of the course of the process in a required direction; controlled factors  $z_1, z_2, z_3, \dots, z_n$  characterize the certain conditions of the road traffic functioning. In the course of the experiment, the mentioned factors are registered with a desired accuracy, though their direct values do not depend on the experimenter – he is not able to influence them; uncontrolled factors  $g_1, g_2, g_3, \dots, g_m$

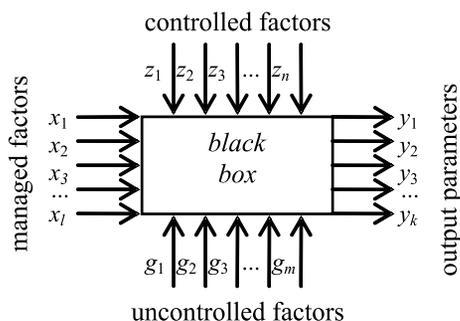


Fig. 1. The scheme of the influence of different factors on the managed object

makes a disturbing influence on the system. It is difficult to get qualitative information about their influence on the system. The criterion for the efficiency of the road traffic system, analogically to the active experiment, are the values of the output parameters  $y_1, y_2, y_3, \dots, y_k$ .

When implementing the evolutionary experiment information on the course of the process is obtained under the conditions of normal functioning of the system, since insignificant changes of the managed factors do not exceed the limits of the operating (usual) regime. Besides, a possibility of multi-recurrence of similar variants of the experiment allows to determine the degree of the influence of each managed factor  $x_l$  on the output parameter  $y_k$  taking into consideration the controlled factors  $z_n$  and uncontrolled  $g_m$  factors, the influence of which is estimated as noise within the process.

Since the variation interval of the managed variables is not large because of various limited conditions, the experimental error slightly increases due to the unmanaged factors and their changes in a real process. In this relation a mathematical processing of experimental data, except of those three inseparable steps (estimate of process reproduction, significance of regression coefficients and the check of adequacy of a mathematical model) has certain peculiarities. Evolutionary planning of the experiment gives a possibility to exclude the influence of the controlled factors and to obtain a reproduction process from the non-reproduction process, i.e. to work with a quasi-reproduction process.

Based on the above-mentioned the evolutionary planning involves the advantages of active and passive experiment, it is one of the methods of adapted optimization allowing to obtain a fuller mathematical description of the system, as a whole.

### 3. Determination of optimization parameter and experimental factors

The optimization parameter includes information on the responsive reactions of the multi-criterion system under consideration to the influence of various factors. Parameters which define the safety and efficiency of the system's functioning are very different. A detailed analysis of the evaluation criteria of the quality and safety of road traffic enabled to identify that a complex and generalized criterion of "potential danger" is able to assess the operation of the whole system and to indicate the ways how to improve the system (Blaeijs *et al.* 2003; Михайлов *et al.* 2004; Врубель 2003; Врубель *et al.* 2006). Moreover, unlike the majority of parameters, it could be applied in any stage of decision-making – in a design stage or after the decision has been implemented. This parameter also meets the specific requirements for optimization parameter in the planning stage of the experiment (Table 1).

The values of managed factors must be defined at predetermined level with the most possible accuracy. Besides, the managed factors cannot be the function of multiple factors and their full combination must satisfy the conformity and safety conditions. In order to define the influence

**Table 1.** Requirements for optimization parameter

Requirement	Characteristic of the conformity of “potential danger“ parameter to the given requirement
Efficiency in respect of achieving the aim	The aim of the experiment is to assess the quality of traffic in the conflict objects of road and street network of cities and settlements. “Potential danger” is a criterion describing the traffic itself as well as traffic conditions. The degree of minimizing a “potential danger” characterizes a possibility to improve the DVRE system in a way of approaching a permissible level of traffic quality, taking into account the accident costs, economic, ecological and social costs. Thus, the criterion does serve the purpose of the research.
Ability of unification or universality, i.e. ability of the parameter to comprehensively characterize the system	“Potential danger” could be applied to all subsystems of the DVRE system. It takes into consideration the dynamic properties of vehicles, geometrical characteristics of streets and roads, traffic conditions, vehicle-pedestrian load, non-uniformity of traffic, the influence of traffic organization and control regimes on the traffic conditions of vehicle and pedestrian flows, the influence of Road Police control and peculiarities of psycho-physiological perception of traffic regimes and traffic organization measures by the drivers, particularity of conflict interaction and also the degree of negative consequences. Without doubt, it is a universal criterion.
Possibility to quantify the parameter in one number	“Potential danger” is expressed in one number and has the dimension of units/year. It allows to determine the quantity values of the levels of road traffic quality.
Statistical efficiency	It is fully ensured by the accuracy of measurements and recurrence of the trials of large sample.
Physical meaning, complete and easy calculations	Physically is classified as rather simple and easy measured criteria of efficiency. Physical meaning of the criterion – is actually a potential of failure, the number of accidents, their severity.

of each factor on the system's operation, it is necessary to have a possibility of defining the value of the factor at pre-determined level, irrespective of the value of other factors. When selecting the factors it is necessary to take into account that, on the one hand, more factors give a more reliable description of the system, on the other hand – the increase in the number of factors leads to a significant increase in the dimension of factor space and the number of trials. Therefore, in order to single out the most significant factors, it is desirable to have a priori information about their influence on the process of traffic in the given conflict object. Due to the specific features of road traffic only a small group of factors can be attributed to the group of managed factors. However, the majority of factors do not meet the requirements for this group of factors. Therefore, based on the current information, the group of managed factors can include the variables which characterize the external effects in the process of road traffic:

- 1) cross section and longitudinal section of the street, its geometrical parameters;
- 2) traffic organization in a conflict object and in its approaches;
- 3) regimes of traffic lights.

The scheme of evolutionary planning of the experiment gives a possibility to take into consideration the influence of uncontrolled factors, the values of which must be recorded during each trial. Here, it is necessary to explain the term “manageability“ for such parameters of road traffic as traffic volume, speed and composition of traffic flow from the point of view of the theory of the experiment planning.

In road traffic, the volume, speed and composition of traffic flow are the main parameters based on which the traffic management is carried out. The only possibility to influence the change of these parameters is to use the methods of traffic organization, for example, to prohibit the traffic of certain types of vehicles on the given section

of the street network, to restrict certain transportation routes, to control speed by introducing a restricted speed regime, clear routing of the shuttle vehicles or by installing physical obstacles (artificial obstacles – rumble strips, speed bumps, etc.). But generally, the change of these factors in space and in time, despite these determinate effects, will remain a random process. Thus, it is practically impossible in each individual case to determine and to maintain the values of these factors on a constant level and with high accuracy. Usually the values of these factors are determined only in the course of experiment or after its execution. However, the main condition for planning and realizing the active experiment is the presence of a possibility to determine the value of the factor on the given level and to maintain it constant in the course of the whole experiment. Therefore, the inclusion of the traffic volume, the composition of traffic flow and the driving speed into the group of managed factors leads to large experimental errors and getting of unreliable models.

Therefore, due to the fact that the mathematical apparatus of evolutionary planning allows creating the group of controlled factors, it is up to the purpose to include into this group: traffic volume, composition of traffic flow, driving speed, angle of interaction between the conflicting traffic and pedestrian flows.

#### 4. Classification of the main researches of road traffic

Researches of road traffic differ in large diversity and are classified in accordance with several features (Hauer 2002; Врубель *et al.* 2006). Besides, different combinations of features are possible and a clear difference between the groups could not be always noticed. A very short description of one variant of the classification is given below (Hauer 2002; Врубель 1996; Врубель *et al.* 2006). Based on this classification, the researches of road traffic are grouped:

- 1 – according to the method of implementation: measurement, inspection, modelling, analysis of documentation, survey (questionnaires);
- 2 – according to depth or level: approximate, evaluative, normal, detail (special);
- 3 – according to the extent: of one parameter, of the group of interrelated parameters, complex;
- 4 – according to the periodicity: onetime, periodical, permanent;
- 5 – according to the place of implementation: chamber-type, natural;
- 6 – according to the purpose: informative (statistical), technological, pre-design, decision-making, control, educational, scientific, judicial-technical;
- 7 – according to the subordination: departmental, interdepartmental.

### 5. Sample and measuring accuracy

In measurements related to road traffic the researcher, as a rule, deals with random variables. Therefore the initial processing and presentation of results must be carried out in accordance with the generally accepted requirements of mathematical statistics. We will overview only some situations related to the accuracy of results and their presentation.

It is known that when studying random variables the accuracy of results depends on the accuracy of the measurements themselves (measurement error) and on the number of taken measurements or on the size of statistical sample (representational error). Since the researcher, as a rule, has no possibility to take measurements by using different methods and the measurement accuracy only slightly depends on him, the total accuracy of the results depends mainly on the sample size. Most frequently namely the sample size determines the expenditures and thus, the possibility of implementing the research, its strategy and tactics.

What concerns presentation of the research results, they must be sufficient and obvious and to a certain extent meet the accepted norms of mathematical statistics. Especially this applies to the main parameters of traffic and pedestrian flows, for example, traffic volume and speed, according to which the largest number of measurements are made.

Measurement results could be presented by:

1. Numerical characteristics of the distribution of the measured parameter. Most frequently the values of expectation and a variation coefficient are presented. Sometimes merely the average value is presented or the value of 85 % of confidence probability. In some cases the distribution law and its characteristics are presented.

Let us remind that the expectation  $x$  is defined by the formula:

$$\bar{x} = \frac{\sum x_i \times n_i}{\sum n_i}, \quad (1)$$

where  $x_i$  – existing value of the argument (average value of the variant);  $n_i$  – frequency (of the given variant). Standard deviation  $\sigma$  is defined by the formula:

$$\delta = \sqrt{D} = \sqrt{\frac{\sum [(x_i - \bar{x})^2 \times n_i]}{\sum n_i}}. \quad (2)$$

Variation coefficient  $I$  is defined by the formula:

$$I = \frac{\sigma}{x}. \quad (3)$$

2. Statistical tables, where the sample is grouped according to one or several features with the presentation of resulting data.

3. Graphical materials between which the most widely used are: polygon, histogram, differential or integral (cumulative) distribution curves, etc.

4. In solitary cases the correlation tables, correlation coefficient, regression equation, graphs of correlation fields, regression lines and other indicators can be presented.

Generally, the correlation coefficient  $r$  is estimated by the formula:

$$r = \frac{\sum (x_i - \bar{x}) \times \sum (y_i - \bar{y})}{n \times \sigma_x \sigma_y}, \quad (4)$$

where  $x_i - \bar{x}$  – deviation of the variable (feature)  $x$ ;  $y_i - \bar{y}$  – deviation of the variable (feature)  $y$ ;  $\sigma_x$ ,  $\sigma_y$  – standard deviations of variables (features)  $x$  and  $y$ ;  $n$  – sample size.

In small samples the correlation coefficient  $r$  is estimated by the formula:

$$r = \frac{\sum (\alpha\beta)}{\sqrt{\sum \alpha^2 \times \sum \beta^2}}, \quad (5)$$

where  $\alpha = x_i - \bar{x}$  and  $\beta = y_i - \bar{y}$ .

The peculiarities of initial processing and presentation of measurement results in implementing separate researches of traffic volume are given below.

### 6. Research of traffic volume

For the optimization of traffic organization it is necessary to obtain a number of initial data which could be divided into two main groups:

- initial data characterizing directly the object or section under consideration. These are parameters of vehicle-pedestrian load and characteristics of traffic conditions. This data could be either given or obtained in a way of experiment;
- initial data related to the general characteristics of traffic losses. These are the indicators of costs and the elements of control effects (measures), dependencies between different parameters, etc. The mentioned data is given in the methodology as a reference material or as different dependencies. They could be obtained and corrected also in the course of serious researches.

In this article we tried to focus on one of the most important parameters – traffic volume.

Multiple researches revealed the interrelation between the accident rate and the volume of traffic and pe-

destrians (Blaeij *et al.* 2003; Davis 2004; Леонович *et al.* 2007). This is a statistical dependency characterized by the growing accident rate with the increasing traffic volume.

In order to develop an adequate mathematical model of the accident rate in road traffic, it is especially important to properly take it into account the effect of traffic volume.

The error of determining the indicator of traffic volume depends on the number of measurements and their duration.

Thus, *the aim* of the work is to get reliable information on traffic volume, to estimate the admissible error in finding the indicator of traffic volume and to select an adequate regime for implementing measurements.

To solve the above task the experimental and theoretical researches were carried out.

Experimental part of the work included the measurements of traffic volume in the city of Minsk, in Knorina street, on the section between the Tolbuchina and Belinskovo streets.

The measurements were taken in Dec and in the 1<sup>st</sup> half of Jan.

In order to eliminate the effect of systematic error, related to the measurements of traffic volume during the whole week, the measurements were carried out on the same day of every week.

Time interval within the limits of which observations were performed was 12 hours: from 9 a. m. to 9 p.m.

The measurements were taken every hour in the following way: they started 5 min to the end of the current hour and ended 10 min after the start of the next hour. For example, the start of the measurements - 8.55 a.m., the end - 9.10 a.m.

As a result, duration of each trial (from the start of the first measurement to the end of the last one) was 15 min.

Duration of a separate measurement within the limits of the trial equals to 1 min.

All the vehicles passing the cross-section of the road within a minute are recorded according to the vehicle type and driving direction.

Such methodology of measurements enables to get an every-minute traffic volume within the limits of each 15 min trial. Since the trials are carried out every hour, the number of trials is determined by the duration of observations: in 12 h regime of observations - 13 trials.

Totally, 7 observations were carried out - one observation in a week, every Thursday.

For the organization of data obtained in the course of experiment, a special computer program was developed.

*The aim* of theoretical research was to select the indicator of traffic volume and to estimate the error of its determination depending on the regime of implementing the measurements.

3 parameters were studied as the possible indicators of traffic volume:

- a traditionally used arithmetic mean;
- parabolic mean, i.e. average value of a polynomial by which a realization of random dependency between the traffic volume on the time of the day was approximated;

- integral mean - average value of the integral obtained in the result of numerical integration of traffic volume in time using the Simpson's method.

Calculations of the traffic volume indicators were carried out by a specially-developed computer programme which uses the database of traffic volume and makes a single package with the programme of database formation. Besides the traffic volume indicators, the program also gives coefficients of approximation polynomial, full and residual variance, the value of Fisher's criterion and the determination coefficient. The program allows making calculations for any number of trials within the limits of their quantity determined by the duration of observations. Also, from the whole number of trials it is possible to take into account either all the trials one after another or to select every second trial, every third trial, etc. Estimation of the average value of traffic volume in the course of one trial can be carried out for different quantity of measurements within the limits of their maximum number.

All the calculations were carried out using the developed software package. First of all, the order of parabola was chosen to approx the data of the trials.

The use of Fisher's criterion enables to make a conclusion about a possible use of a 2<sup>nd</sup> or 3<sup>rd</sup> degree parabola as an approx polynomial. Further, a parabolic mean is calculated in respect of a 2<sup>nd</sup> degree parabola.

The next stage of research was focused on studying the effect of the measurement implementation regime on the error of determining the traffic volume indicators. For this purpose the values of traffic volume indicators were calculated by the different combinations of the number of trials and the number of points of the averaging of traffic volume within the limits of the trial.

Maxi 13 trials were selected from the formed database within the interval of observations from 9 a.p. to 9 p.m, i.e. duration of observations was 720 min. From this sequence of the trials the sampling was made every 2, every 3, every 4 and every 6 trials, in the result of which the sequences of 7, 5, 4 and 3 trials, correspondingly, were obtained.

In each sequences the intervals between the adjacent trials are constant. Preliminary calculations showed that the use of sequences consisting of 3 or 4 trials leads to large errors of determining the indicators of traffic volume; therefore, in the next researches the sequences of 5, 7 and 13 trials were used. Within the limits of each trial sequence, the indicators of traffic volume were calculated at 2, 5, 10 and 15 points (measurements) of the averaging of traffic volume. Since the duration of one measurement is 1 min, the given duration of the trial in min is numerically equal to the quantity of the trials based on which the averaging is carried out, i.e. 2, 5, 10 and 15 min. Such calculations of traffic volume indicators were carried out for each of 7 observations. The error of determining the indicator of traffic volume was estimated by its relation to the value of the indicator obtained by using the sequence of 13 trials and 15 min duration of the trial.

Since the indicators of traffic volume, as well as their relative errors, are random variables, the upper confidence limits of relative errors were determined.

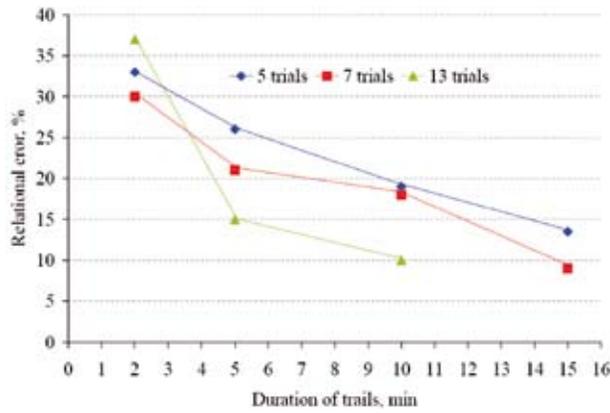


Fig. 2. Upper confidence limits of the error of arithmetic mean

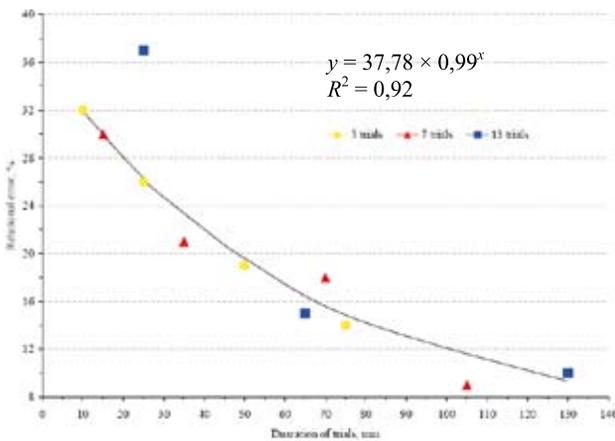


Fig. 3. Dependence between the error and the total duration of trials

Fig. 2 gives the dependencies between the upper confidence limit of a relative error of arithmetic mean and the duration of the trial in case of 5, 7 and 13 trials.

The charts show that, if the duration of the trial is less than 4–5 min, the number of trials has no significant influence on the size of the error. The same values of the error of traffic volume indicator can be obtained by combining the different number of trials and their duration.

For example, the upper confidence limit of the error not exceeding 15 % is reached after 13 trials with the duration of 5 min each or after 5 trials with the duration of 15 min each. The error under 10 % can be obtained after implementing 13 trials with the duration of 10 min or 7 trials within 15 min.

A point-by-point diagram in Fig. 3 describes the relation between the error of arithmetic mean and the total duration of the trials (reliability of the estimate – 90 %, confidence probability – 90 %).

The total duration of trials  $T_3$  is the product of the number of trials and duration of the trial. Fig. 3 shows that nearly all the points of the diagram are located close to a certain curve. This means that within the range of the adopted values of the number and duration of trials the error of the traffic volume indicator depends mainly on the total duration of trials. The point  $T_3 = 26$  min and  $N = 13$ ,

Fig. 4. Interactive window for the input of traffic volume

Fig. 5. Interactive window for the input of traffic volume

corresponding to the duration of 2 min, proves once again that such a duration of the trial is inadmissible.

The Fig. 3 enables to determine the required duration of the trial depending on the number of trials or, vice versa, on the given calculation error. In order to get the error of arithmetic mean not exceeding, for example, 10 % the total duration of trials must be at least 110 min, i.e. in case of 5 trials, the duration of each trial will be 22 min.

A computer program has been developed enabling to formalize the input of initial data and their processing and aimed at the execution of the further engineering calculations (Fig. 4).

For eliminating the results of improper (erroneous) data input, the program gives a possibility to bring back the last operation (“BACK”, and then “NEXT”). Having finished data input, the calculations are carried out with an automatic request to save the output information which could be viewed right away.

Where it is necessary to determine a potential danger in another conflict point, the screen is automatically renewed, the previously entered information is stored and a new input of information or a correction of the previously entered information is carried out. Data on the results of the use of the program which are automatically saved and could be printed contains initial data with the names of the

corresponding variables under which they are used in the program, also data on the calculation results in the object under consideration (Figs 5, 6).

The computer program has a certain commercial potential and gives a possibility to form the bank of initial data based on the characteristics of traffic flows, traffic conditions and accident statistics in the objects under consideration.

The developed computer program makes it possible to automate the input, processing and systemization of initial data for further optimizing calculations of the parameters of traffic-light cycle. This helps to significantly reduce the labour costs and time used for forecasting, allows to put into the practice of traffic organization the improved forecasting method and to improve traffic safety in unsignalized intersections.

The computer program makes it possible to independently process the data of traffic volume either in the “Krest Inp” environment or by representing the cartogram of traffic volume (Fig. 7), the diagrams of traffic flow composition and traffic non-uniformity (Fig. 8).

### 7. Conclusions

It was determined that, when studying processes related to road traffic, an evolutionary experiment must be used encompassing the advantages of passive and active methods.

In order to get reliable information about the parameters of the system’s functioning, it is necessary to precisely plan the implementation of experimental researches (data collection – implementation of a field experiment). Besides, it is necessary to observe requirements of mathematical statistics in order to substantiate the sizes of samples and the accuracy of measured parameters.

The implemented researches enable to make the following conclusions related to the studies of traffic volume: duration of one trial must be at least 5 min; the number of

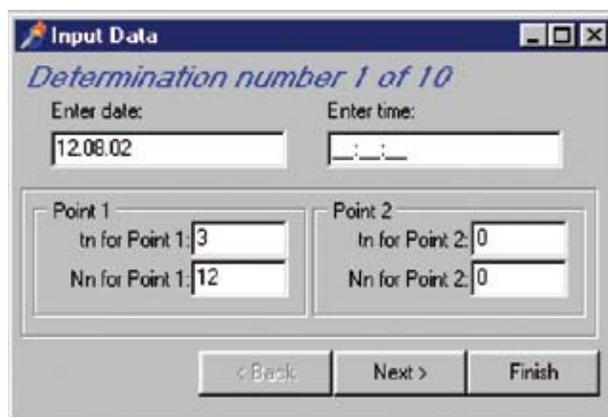


Fig. 6. Interactive window for the input of parameters to calculate the flow distribution

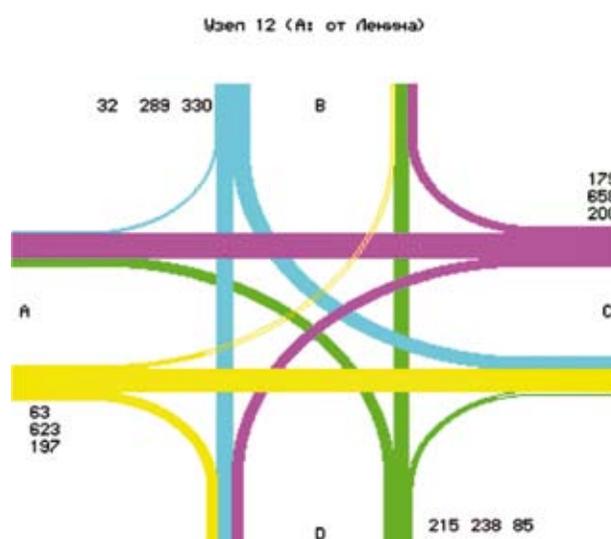


Fig. 7. Cartogram of traffic volume

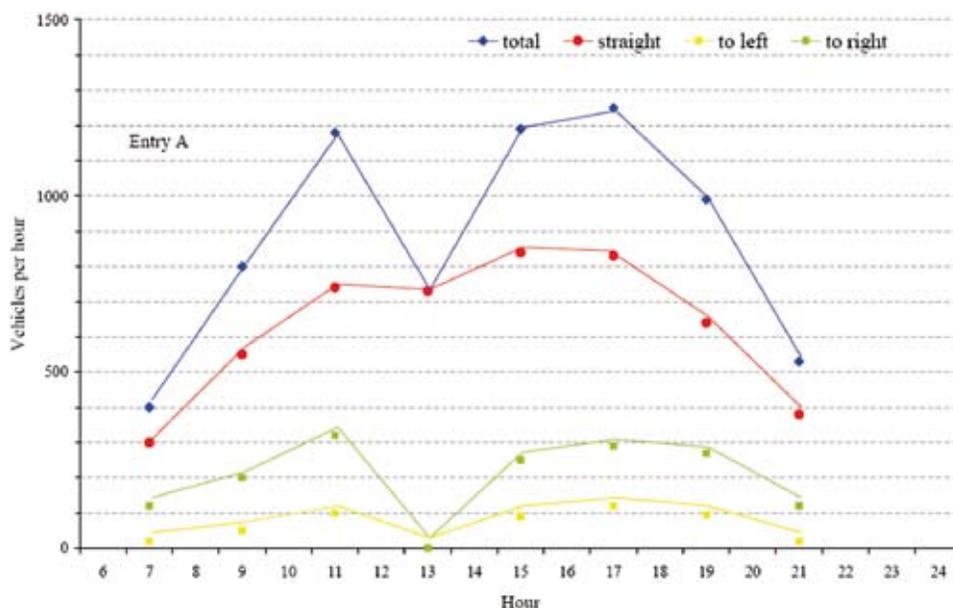


Fig. 8. Graph of traffic non-uniformity

trials and duration of each trial must be selected in a way that the total duration of measurements assures the required measuring accuracy, for example, the total 75 min duration of measurements will allow getting the error of arithmetical mean not higher than 16 %, where the confidence probability is 90 %; arithmetic mean of the values of traffic volume, obtained in each trial, could be taken as the indicator of traffic volume.

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