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ESTIMATING PARAMETERS FOR TRAFFIC FLOW USING NAVIGATION DATA ON VEHICLES

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Abstract. The article describes the method for estimating transport flow parameters using the two-fluid Herman-Prigogine mathematical model developed considering the proposed method of estimating parameters for the system based

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on the passive processing of navigation data on the movement of vehicles. The efficiency of the suggested algorithms and mathematical models for estimating road traffic flow parameters and the system as a whole was confirmed performing tests using a set of tracks on the main highways of Belarus.

Keywords: mathematical model, navigation system, parameter, traffic flow, vehicle.

Introduction

At present, traffic congestion on road networks is a burning transport-related issue in most developed countries worldwide. The posed problem is typical of the city street and urban road network where most of the fleet of personal vehicles is concentrated as well as of significant highways and transport corridors carrying significant volumes of freight and passenger traffic.

Considerable experience in implementing measures aimed at solving the encountered problem has been accumulated worldwide so far. The imposed measures fall into three broad groups:
- measures aimed at increasing maximum road network capacity (construction and reconstruction of road facilities);
- measures aimed at increasing the efficiency of using the capacity of the existing road network (improving traffic management);
- measures aimed at regulating the volume and structure of transport demand (introducing various restrictions on the movement and parking of vehicles; reducing the need of the economy and population for transport through measures for spatial planning).

The basis for developing the employed measures and the adoption of scientifically grounded solutions for implementing them act as the application of mathematical modelling methods for the functioning of the available and planned transport systems.

Predicting the effect of various measures aimed at managing road network capacity requires solving various problems of transport simulation:
- predicting the effect of constructed or reconstructed road facilities requires simulating the distribution of traffic flows over the road network;
- assessing the effectiveness of measures for improving traffic management, as a rule, requires simulating the movement of individual vehicles in traffic flow;
- assessing the effectiveness of measures for regulating transport demand requires simulating the volume and structure of the need of the population and economy for driving.

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The necessity for using transport models continues to grow. Transport systems evolve due to the expansion and development of road network connectivity, the increased role of multimodal transport and the introduction of intelligent transport systems. Thus, the acute problem of congestion on the road networks of major transport corridors and cities is worsening.

Wisely chosen criteria and methods for assessing traffic flows are required to use appropriate mathematical models for providing decision-making on the management of transport flows.

1. Choosing optimal criteria for assessing traffic flows and the method

For estimating street and road networks, a variety of tasks and situations arise, thus resulting in the need for using a number of partial and integral criteria for assessing traffic flows.

Partial criteria in consonance to nature are divided into the ones used only as descriptors and those employed as parameters for the management process. The latter include the average and total delays, queue length and leg length minus queue length.

The most significant criterion for the economic assessment of national traffic management is often considered to be the transport operation of the street and road network.

Another criterion is the stability of street and road network functioning. The indicator is defined (Dryu, 1972) as a property allowing to reduce the capacity of the road as a result of a full or partial failure in assessment elements. A failure is considered as a change in road traffic conditions resulting in an infrastructure element of the street and road network being partially or entirely excluded from the transport process.

The criteria based on the magnitude of the delay and queue length have been singled out.

The duration of the average delay of the vehicle has been widely used as a criterion for optimising traffic control at a separate intersection. It has been determined that the average delay closely correlates with such indicators as the total delay, queue length, traffic volume and parameters for the traffic control mode.

Queue length means the number of vehicles in the queue or the length of the queue in linear units. This parameter is closely correlated with the average and maximum delays, traffic volume, parameters for the traffic control mode and affects indicators like traffic speed and the number of starting and braking per unit of length.

Queue length is used as an indicator for a degree of saturation comparing to queue length passed per cycle. When the state of saturated flows is reached, queue length and the related indicators are considered to be the most acceptable for network management. In this case, the task of management is to minimise the probability of congestion.

The cost-effectiveness of road traffic is estimated in consonance to several criteria the most important of which include a specific delay and specific stop calculated per vehicle (Mikhaylov & Golovnykh, 2004; Vrubel', Kapskiy, Rozhanskiy, Navoy, & Kot, 2011).

The density of street and road networks is defined as the ratio of the total length of streets and roads to the size of the area. The density of street and road networks and their traffic load indicators were considered in a number of authors. Typically, the subject of the conducted research is statistical data on the indicators like the density of street and road networks, the length of streets and roads per capita, the number of the registered vehicles per 1 km of streets and roads and the annual mileage of vehicles per 1 km of streets and roads.

A number of studies have been devoted to establishing a connection between density and capacity indicators. The most important drawback of the density indicator and its modifications is the absence of specific information about any street and road section. In general, density indicators, as mentioned above, are descriptors and give only a general assessment of the state of the network.

For using partial criteria, the question about indicators to be given preference and the cases of applying them arises. Thus, it is impossible to find an unambiguous answer to this question.

However, a significant number of specialists prefer the average delay value of vehicles as the most objective indicator for the quality of traffic control and management.

In the case of traffic flows of heavy vehicles, it is most expedient to estimate traffic conditions by the magnitude of the vehicle queue at the intersection or in line to the indicators based on vehicle queue:
- a ratio of queue length to leg length;
- leg length minus queue length.

The conducted constant search for universal integral criteria allows assessing both the quality of road traffic in general and the quality of road traffic individual properties since it is impossible to evaluate with the help of partial criteria.

Dryu (1972) proposed a valuating integral quality criterion for road traffic – Level of Service (LOS) that means the qualitative state of traffic flow under typical traffic conditions. The Level of Service is related to such factors as traffic safety, operating speed, driving comfort and

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convenience, the freedom of manoeuvring, flow interruption and travel costs.

The use of the above-introduced criterion covers all stages of work on street and road networks, including planning, design and operation. The LOS criterion is used for estimating traffic conditions in both street and road network simulation programs and highly specialised intersection and junction design programs.

One of the drawbacks of the considered criterion is LOS difficulty and qualitative assessment as a whole and sometimes – the impossibility of the quantitative assessment of effective individual solutions.

Vrubel' (2003) proposed a valuating integral criterion loss in road traffic. The losses are understood as the socio-economic value of the unenforced costs of the movement process.

This criterion is applicable for assessing the quality of both road traffic in general and losses in road traffic individual properties. Quality assessment is carried out in monetary terms providing a possibility of comparing the quality of the individual properties of road traffic and the costs of road traffic accomplishment. This fact makes the comparison very clear and allows easily and quickly optimising solutions for traffic management under the criterion for loss minimisation.

Variations in traffic flow operating speed are viewed as an integral criterion. A significant variation in speeds is a distinctive feature of modern urban traffic on street and road networks. The speed ranges from 60 km/h allowed within the city limits to 5–10 km/h or less established in the cases of congestion.

Variations in traffic flow operating speed assess the influence of the whole set of factors in a wide range of their changes starting from free-flow conditions and ending with congestion situations.

Thus, integral criteria are the most applicable to solving problems arising from the assessment of the street and road network.

When using integral criteria for assessing the quality of traffic management, methods for mathematical modelling are inevitably applied regarding macroscopic models for traffic flow. In this regard, the integral criterion for assessing the quality of traffic management is developed on macroscopic models for traffic flow.

Historically, the first macroscopic model for the single-lane traffic flow was the one later named the Lighthill-Whitham-Richards model (Lighthill & Whitham, 1955; Richards, 1956). Vehicle flow of the model was regarded as a flow of one-dimensional compressible fluid.

The Lighthill-Whitham-Richards model assumes that
- there is a one-to-one relationship between speed and the linear density of the flow;

- the law of the conservation of mass – the number of vehicles is fulfilled.

Another version of the Lighthill-Whitham-Richards model was proposed by Tanaka in 1963 (Gartner, Messer, & Rathi, 2002; Inose & Khamada, 1983).

The Tanaka model assumes that the vehicle speed fails to exceed a specific maximum value, and therefore the density of the single-lane traffic flow is calculated. This model plays an essential role in the study of traffic flows in terms of traffic safety.

The Payne (1971) model hardly raises any assumptions about the dependence of speed on density and is written as a conservation law.

Several drawbacks of the Payne model and many of those subsequently proposed were indicated by Daganzo (1997) (Shvetsov, 2003). They showed that the strong spatial inhomogeneities of the initial conditions resulted in the negative values of speed (congestion "dissipates back" as a result of viscosity influence). For specific parameter values, density exceeding the maximum permissible values occurs ("bumper to bumper"). Moreover, these models indicate that vehicle movement is significantly influenced by transport means located behind. In the case of a single lane, it is hardly possible in the real-life traffic flow.

One of the macroscopic model varieties presents the two-fluid Herman-Prigogine mathematical model (Herman & Prigogine, 1979) that considers nonlinear dependency on specific travel time and specific time of delays expended per unit of distance. The scope of using this model is the street and road network or appropriate sections of the network.

Since the kinetic theory studies multilane traffic, Herman & Prigogine (1979) put forward the theory of two urban traffic flows. Vehicles fall into two groups in the traffic flow – moving and stopped vehicles. The latter include the vehicles stopped in the flow, i.e. at intersections, stopped due to regular congestion or interference to traffic but excluding out-of-traffic vehicles, for example, the parked ones.

An essential property of the Herman & Prigogine macroscopic model (1979) displays two different traffic operating modes, including individual and collective flows functionally dependent on the concentration of vehicles – flow density. Under low flow density, traffic moves in the individual flow mode. However, an increase in flow density makes traffic start moving in the collective flow mode. Thus, the flow becomes mostly independent of the desires of individual drivers when choosing the driving mode.

The two-flow model is based on two initial assumptions:
- the average operating speed along the street and road network is proportional to the fraction of the vehicles in motion;

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- the duration of delays of a vehicle moving along the street and road network is proportional to the number of vehicles stopped at a given time.

The studies confirmed the provisions of the two-fluid Herman-Prigogine mathematical model (Nelson & Sopasakis, 1998). At the same time, it was established that urban street networks were characterised by two parameters for the model – n and T_m calculated based on experimental data obtained from the surveys of cities worldwide.

The Herman-Prigogine model is very efficient for practical use and easily applicable to conducting regular surveys of traffic conditions in comparison to other macroscopic models. The uniqueness of the model is that for assessing the impact of the street and road network load on traffic conditions, determining the load level is unnecessary, i.e. traffic volume and the capacity of the elements of the street and road network are irrelevant. Only data on specific indicators for travel time T and standing time T_s are needed to assess parameters n and T_m.

The Herman-Prigogine model is applied:
- for comparing the street and road networks of different cities or contrasting sections within one street or road network;
- for comparing the peculiarities of driver behaviour and the movement of certain types of vehicles;
- for giving a detailed assessment of the influence of geometric parameters for the street and road network on traffic conditions;
- for assessing the estimated traffic conditions in the simulation of traffic flows.

2.   Description of the traffic flow model

The parameters used in the Herman-Prigogine model consisting of two flows (moving and standing vehicles) represent the average data determined on the scale of the complete street and road network for a given period.

Under the above provisions, the traffic flow on the street and road network consists of two parts at any time and is represented by f_r – moving vehicles and f_s – standing vehicles. In this case, condition $f_r + f_s = 1$ is observed, and the fraction of standing vehicles f_s is determined by the ratio (Eq. (1)):

$$f_s = \frac{1}{T_s}.$$
(1)

The average specific time expenditure T (min/km) (Eq. (2)) is the sum of the average specific travel time T_r (min/km) and specific delay time T_s (min/km):

$$T = T_r + T_s. \tag{2}$$

The average speed of moving vehicles V_r (Eq. (3)) is defined as the product

$$V_r = V_m f_r^n. \tag{3}$$

Considering delays, the average operating speed on the street and road network or its considered section V is calculated as (Eq. (4))

$$V = V_m f_r^{n+1}. \tag{4}$$

Regarding balance equation $f_r + f_s = 1$, Eq. (4) is represented in another form (Eq. (5)):

$$V = V_m f_r^{n+1} = V_m (1 - f_s)^{n+1}. \tag{5}$$

Accepting travel time per unit of length as T, travel time per unit of length as T_r and the average delay time for the passage of a section of unit length as T_s, the following relations (Eqs (6) and (7)) are obtained:

$$T = \frac{1}{V}, \tag{6}$$

$$T_m = \frac{1}{V_m}. \tag{7}$$

Parameter T_m characterises minimum specific time expenditure for moving under free conditions, i.e. at an extremely low level of network load rejecting the interaction among the vehicles in the flow.

In turn, parameter n is called the Herman-Prigogine criterion and reflects the influence of the load level on a decrease in the operating speed of traffic flows. It is considered an indicator of the quality of the service of traffic flows on the street and road network.

The second initial provision of the two-fluid model asserts that the duration of delays of a vehicle moving along the street and road network is proportional to the number of the vehicles stopped at a given time. Subsequently, the second assumption of the model is mathematically represented by Eq. (8):

$$f_s = \frac{T_s}{T}. \tag{8}$$

Eq. (5) is reformulated to estimate travel conditions in line to specific time expenditure as follows (Eqs (9)–(11)):

$$T = T_m (1 - f_s)^{-(n+1)}; \tag{9}$$

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$$T = T_m \left[1 - \frac{T_s}{T} \right]; \tag{10}$$

$$T_r = T_m^{\frac{1}{(n+1)}} \cdot T^{\frac{1}{(n+1)}}. \tag{11}$$

The general formula of the Herman-Prigogine model becomes as follows (Eq. (12)):

$$T_s = T - T_m^{\frac{1}{(n+1)}} \cdot T^{\frac{1}{(n+1)}}. \tag{12}$$

The model and Herman-Prigogine criterion n represented above make it possible to obtain a systematic assessment of the transport situation on the street and road network as a whole, i.e. to quantify the sensitivity of traffic conditions to a change in the load of the street and road network.

The logarithmic transformation of Eq. (12) is Eq. (13)

$$\ln T_s = \frac{1}{(n+1)} \ln T_m + \frac{n}{(n+1)} \ln T. \tag{13}$$

To use linear regression, Eq. (13) is transformed in Eq. (14)

$$\ln T_s = \ln T_m + n(\ln T - \ln T_m). \tag{14}$$

The linear dependence equation simplifies the procedure of regression analysis and allows using standard statistical methods for estimating traffic flow parameters.

The classification of road networks based on the parameters included in the Herman-Prigogine model allows predicting traffic speed and time expenditure for travel at any given section of the road network. The classification is constructed, for example, using the clustering analysis of the experimentally established values of travel time parameters T and standing time T_s.

3. Implementing an assessment system for traffic flow parameters

An integrated assessment of traffic management quality is made based on the Herman-Prigogine model using the data obtained from navigation equipment.

Satellite monitoring of transport is applied for dispatching control over and management of passenger transport and solving the problems of transport logistics in transportation management systems and automated fleet management systems. Satellite monitoring of transport is a system for monitoring mobile objects based on satellite navigation

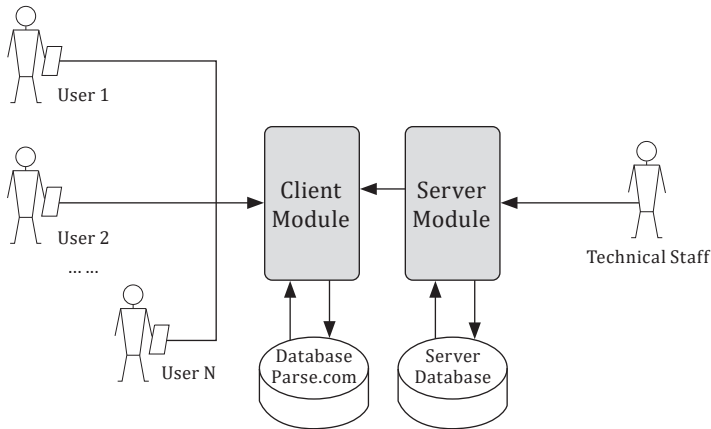systems, cellular and radio communication equipment and technologies, computer technology and digital maps.

The principle of monitoring covers tracking and analysing the spatial and temporal coordinates of a vehicle. Two monitoring options such as "on-line", including the remote transfer of coordinate information, and "off-line", embracing information read upon arrival at the dispatch centre are available. A mobile module is installed on the vehicle and consists of a satellite receiver, storage and transmission modules in coordinating data.

Data on specific indicators for travel and standing time are actively collected employing a specially equipped vehicle for driving through the examined sections of the street and road network.

A passive system is also applied and comprises specific indicators calculated regarding navigation data collected from various vehicles involved in road traffic. Such data are obtained from different sources like the servers of a transportation company. The passive approach to data collection allows increasing the accuracy of the system since more data are examined than gathered from different vehicles controlled by different drivers.

The methodology of the passive experiment, along with the use of the Herman-Prigogine model, allows examining traffic flow parameters and constructing a decision-making support system for controlling transportation, selecting traffic routes and assessing possible changes in the transport system.

Using the two-fluid Herman-Prigogine model, a software system has been implemented and allowed making a quantitative assessment of traffic parameters using navigation data as well as visualising them using the Google Maps geographic information system (Figure 1).

Figure 1. System architecture

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The software system is designed to collect and analyse navigation data on the further application for assessing traffic flow parameters based on the two-fluid Herman-Prigogine model (Blinkin, & Tkachenko, 2009; Nelson & Sopasakis, 1998; Prigogine & Herman, 1979). The data are collected using a large number of navigation modules installed on the vehicles or smartphones of users. Data analysis is performed centrally on a high-performance computer, as it requires a considerable amount of calculations.

The software package proposed for the solution of the above-introduced tasks is implemented on the client-server architecture basis (Ill. 1, Ill. 2). Thus, the data received from clients are transferred to the server end for further storage and processing and analysing the obtained information (Figure 2).

The client end is represented by two types of equipment – a built-in navigation module integrated into the vehicle or a mobile application based on the Android OS. The built-in equipment automatically sends data on the vehicle location to the transportation company performing preliminary data collection with the subsequent provision of the system under consideration. The second case is a client application installed on the mobile device of the user.

To send tracks, users must have a Global Positioning System (GPS) receiver activated on a smartphone or a vehicle and enable data transfer. When driving over a certain period, users receive their current location. Also, an attempt is made to obtain the name of the street for the current coordinate. The client end of the application analyses the received information and calculates parameters like time, speed, coordinates on GPS basis.

User data are sent to the cloud server Parse.com for further storage and exported in the required format. The Parse.com library was used for processing data for Parse.com.
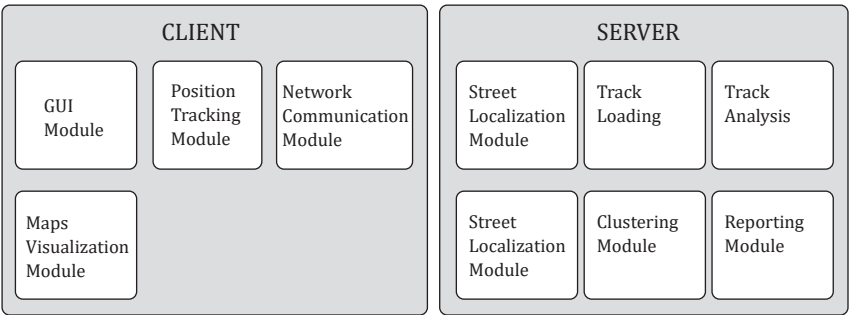
Figure 2. The composition of the client and server subsystems

The implementation of the client end is represented by a mobile software system for data collection. The system was developed for the Android platform using the Java programming language. The user interface of the system was developed next to the requirements set by Google for the interface of Android applications.

The server end of the system is a web application used for
- loading tracks from a file;
- processing tracks in line to the Herman-Prigogine model;
- visualising the obtained results with an overlay on the Google Maps cartographic service (Google Maps Javascript API);
- clustering the sections of the street and road network in consonance to parameters for the Herman-Prigogine model.

Following the preliminary processing and storage in the cloud service, data are uploaded as a file for further analysis. The file in the CSV format is sent to the server end of the system that receives all tracks from the file at this stage, processes and verifies them. Then, the file in the CSV format containing tracks is sent to the input for analysis. After receiving all tracks for a particular street, the number of tracks, standing time and the average speed for this section of the road are determined. Every parameter is assigned a threshold value in advance and assists in determining whether a track belongs to the group of unreliable tracks.

After passing verification, data are sent to the Herman-Prigogine module in calculating parameters. The following algorithm is used for implementing the Herman-Prigogine model. All tracks for a particular street are selected from the database of heavy vehicles. Information on time and speed at each point in time-related to obtaining the location is extracted from them. Information on time allows calculating the total travel time and speed allows determining standing time. Thus, the two components necessary for the Herman-Prigogine model are obtained. Next to receiving data, linear regression is constructed using the total and motion time to solve equation $y = kx + b$. After solving linear regression, parameters k and b are calculated and used for estimating parameters for the Herman-Prigogine model.

The data are transferred to the clustering module input, succeeding the calculation of parameters for the Herman-Prigogine model. The FOREL algorithm (Algoritmy semeystva FOREL) is used for clustering the obtained results. The algorithm is based on the idea of combining objects into a single cluster in the areas of the highest concentration and has been chosen due to low demand for specifying the number of clusters in advance. Clustering the entire sample results in the application displaying the charts and routes on the map and then compiling a report in the TXT format.

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The implementation of the server end is represented by a unique system created for the web platform (jQuery API Documentation; Matplotlib; SQLite Documentation). Python was used for developing the primary programming language. The Flask framework was employed for displaying in the web environment. Cartographic service Google Maps v3 (Location and Sensors APIs) was applied in this system. The JavaScript programming language (jQuery API Documentation) was used for manipulating the map: constructing points and routes. ORM SqlAlchemy and the SQLite database management system (SQLite Documentation) were utilised for work on the database. The use of this Database Management System (DBMS) is rational within this paper because of the mobility of deployment and maintenance. For developing the introduced system in the future, using a more powerful DBMS is required, as the increased amount of data leads to limitations to the existing solution.

Thus, the hardware of the software package for assessing traffic flow parameters includes

- a mobile device for collecting traffic information – a navigation module integrated into the vehicle or a mobile device with a GPS receiver (Android OS 4.0 and higher) having the enabled function of data transfer;
- software products of transportation companies providing navigation data in the CSV format;
- the automated workstation (AWS) of the operator, including a personal computer running the Linux family in the operating system. The virtual environment was used for developing the AWS and the Flask framework, and the web application was designed employing the Python programming language (Lutts, 2010);
- SDK Parse.com (Parse Android Developers Guide) for Android OS is a library simplifying work on the Parse.com platform of mobile devices;
- Parse.com cloud service (Parse Android Developers Guide) for storing data transmitted from customers.

4. Testing the software package for assessing traffic flow parameters

The working efficiency of the proposed algorithms, mathematical models for assessing traffic flow parameters and the system as a whole, was confirmed during testing using a set of tracks on the main highways of Belarus. Similar calculations were made for the city of Minsk where streets functioning at the limit of their capabilities were identified.

The routes received from one of the transportation companies of the Republic of Belarus with a volume of 5 million entries were used to verify the functioning of the Herman-Prigogine model as part of the software package for assessing traffic flow parameters. A list of tracks for each street or route obtained beforehand was applied. Next, calculating parameters for the Herman-Prigogine model of each street was necessary.

The parameters were calculated as follows:

- two types of time, including total travel time and standing time, were distinguished for each track. The vehicle was in-moving or standing position to determine what state and a speed limit of 5 km/h were adopted. In the case speed was below the set limit, the vehicle was considered standing, and in the case of a higher speed, the vehicle was accepted as moving;
- after receiving the time of all tracks, the collected data were sent to the Herman-Prigogine model to obtain the result as a report file containing the following information on each route:
- route number – position number of the route in the list of streets or routes;
- address – street, city, country for the current route;
- the starting point and endpoint – route boundary;
- straight-line distance – the distance among the points in a straight line;
- road distance – the distance among the points along the road in compliance to traffic rules on this route;
- speed – minimum average speed obtained as a result of the conducted analysis;
- a table with intermediate data – a table containing all tracks for this route in the form of the total travel time and standing time; the table also contains intermediate computational values;
- adjustable parameters for $y = kx + b$ – adjustable parameters k and b obtained while solving linear regression;
- parameters for the Herman-Prigogine model: the Herman-Prigogine indicator, the average minimum travel time and the average minimum specific travel time.

As a result of testing the subsystem for model calculations, data on parameters n and T_m were obtained and characterised the quality of traffic management in this section.

Having obtained the results of calculating parameters for the Herman-Prigogine model for the specified streets of the city of Minsk, the points of minimum average specific travel time T_m. Moreover, indicator n for Herman-Prigogine model of these streets were plotted on the graph (Figure 3). Thus, the points are located irregularly and form street clusters just as the quality of traffic management.
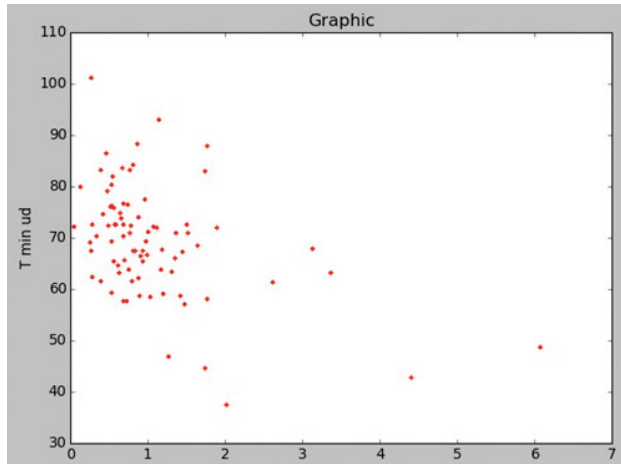
Figure 3. A visualisation graph of calculation results as stated in the Herman-Prigogine model

The FOREL algorithm was chosen for clustering the received data set since the number of clusters obtained at the output was unknown in advance. The algorithm requires specifying only the initial size of the expected clusters. By specifying the radius experimentally, the obtained output was a list of points with automatically generated cluster classes.

The obtained clusters with a radius of seven units are shown in Figure 4.
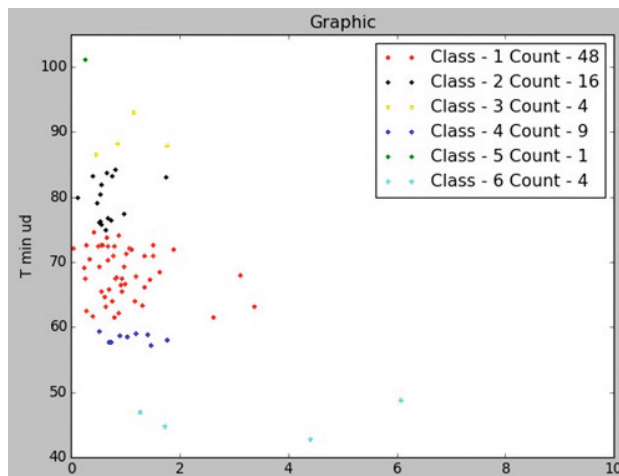
Figure 4. Clustering routes with a radius of seven units

Table 1. The characteristics of the obtained clusters

Cluster number	Number of streets	Range n	Range T	Brief description
1	48	[0.04; 3.36]	[61.51; 74.70]	Moderate response to increased street load
2	16	[0.12; 1.74]	[74.91; 84.30]	Weak response to increased load
3	4	[0.45; 1.76]	[86.60; 93.09]	Weak response to increased load
4	9	[0.52; 1.76]	[57.21; 59.39]	Weak response to increased load
5	4	[1.26; 6.07]	[42.86; 48.76]	Maximum response to increased load
6	1	[0.26; 0.26]	[101.17; 101.17]	No response to increased load

Figure 4 shows that the routes were divided into six clusters, each with a different number of streets. Parameters for each cluster are given in Table 1.

A brief description of road conditions is given for each cluster determined based on a comparison of indicators for other cities. Thus, a conclusion on the characteristics of traffic management in Minsk has been made. Also, the degree of traffic flow load influence on the quality of service was determined in the column of the "Brief description" of Table 1.

The resulting route clustering was applied when plotting the routes on the map in different colours subject to the class of the route. The received data allow visually identifying road sections under different road conditions. Visualisation results are shown in Figure 5.

Figure 5. Colour differentiation of routes by classes

Table 2. The distribution of the streets of Minsk by clusters

Cluster number	Street name
1	Igumensky trakt;
	Rokossovskogo avenue;
	Radialnaya street, section 1;
	Akademicheskaya street;
	Kozlova lane;
	Svislochskaya street;
	Plekhanova street;
	Denisovskaya street;
	Partizansky avenue, section 1;
	Partizansky avenue, section 2;
	Partizansky avenue, section 3;
	Tolstogo street;
	Sverdlova street;
	Nezavisimosti avenue, section 1;
	Nezavisimosti avenue, section 2;
	Nezavisimosti avenue, section 3;
	Nezavisimosti avenue section 4;
	Kizhevatova street;
	Kazintsa street;
	Aerodromnaya street;
	Zhukova avenue;
	Maksima Bogdanovicha, street section 1;
	Maksima Bogdanovicha street, section 2;
	Nemiga street;
	Dzerzhinskogo avenue, section 1;
	Dzerzhinskogo avenue, section 2;
	Pritytskogo street;
	Kalvariyskaya street;
	Pobediteley avenue, section 1;
	Pobediteley avenue, section 2;
	Pobediteley avenue, section 3;
	Masherova avenue, section 1;
	Masherova avenue, section 2;
	Masherova avenue, section 3;
	Timiryazeva street, section 1;
	Timiryazeva street, section 2;
	Timiryazeva street, section 3;
	Klary Tsetkin street;
	Kozlova street;
	Dolgobrodskaya street, section 1;
	Kuybysheva street;
	Surganova street;
	Vaneyeva street;
	Vaupshasova street, section 1;
	Vaupshasova street, section 2;
	Trostenetskaya street;
	Dolginovsky trakt;
	Volodko street

Table 2. Continuation

2	Radialnaya street, section 2;
	Aranskaya street;
	Mogilyovskaya street;
	Brilevskaya street;
	Pushkina avenue;
	Maksima Goretskogo street;
	Pritytskogo street; Storozhyovskaya street;
	Timiryazeva street, section 4;
	Ulyanovskaya street;
	Pervomayskaya street;
	Kuybysheva street;
	Smolenskaya street;
	Maksima Bogdanovicha street, section 3;
	Kuntsevshchina street;
	Volgogradskaya street
3	Yanki Luchiny street;
	Stoletova street;
	Surganova street;
	Platonova street
4	Mayakovskogo street, section 1;
	Tashkentskaya street;
	Kabushkina street;
	Mayakovskogo street, section 2;
	Zhukova ave.;
	Kharkovskaya street;
	Pobediteley avenue;
	Filimonova street;
	Yakuba Kolasa street
5	Moskovskaya street;
	Yanki Kupaly street;
	Dolgobrodskaya street, section 2;
	Dolgobrodskaya street, section 3
6	Korzhenevskogo street

The distribution of the streets of Minsk by clusters is given in Table 2.

Thus, the classification of the streets of Minsk sorted considering the quality of traffic management has been obtained, problematic streets have been identified, and the findings have been visualised.

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Conclusions

1. Mathematical modelling plays an increasingly important role in methodological support for developing and implementing any measures for managing road network capacity. The application of mathematical models in planning management activities in the field of transport offers the opportunity:
   - to assess the quality of traffic management;
   - to predict the operational efficiency of management activities and their combinations based on the obtained estimates;
   - to predict possible negative consequences of implementing management activities.
2. Made predictions and estimates allow significantly improving the quality of management decisions in the transport sector.
3. The widespread introduction of navigation systems in transport opens up strong possibilities of collecting information on traffic flows. The advanced mathematical tools assist in finding solutions for the encountered problems of transport simulation and in assessing traffic flow parameters.
4. Thus, to successfully apply mathematical modelling methods of the transport system, recommendations for transport simulation and the programs optimising road network capacity need to be developed.
5. As part of this paper, a software system has been designed. It includes modules in collecting navigation data, storing and verifying track data, managing street and road data, calculating indicators for the Herman-Prigogine model and classifying streets in line to the parameters based on passive processing of navigation data on vehicle traffic on highways as well as on the streets and road networks of cities.
6. The main advantages and novelty of the developed system include:
   - cloud computing (large amounts of cloud storage data);
   - availability of a mobile client application for the Android OS for collecting data in addition to the ability to work on the navigation data already collected from the navigation and information centre or other sources;
   - support for the formats of modern Global Positioning System trackers;
   - use for calculating and processing data on modern web technologies;
   - the scalability and customizability of the system.
7. As a result of testing the developed software, the findings confirming the working efficiency of the proposed algorithms

have been obtained. Thus, using navigation data collected in the Republic of Belarus, particularly in the city of Minsk, the ability of the software system to distinguish street classes under different conditions of traffic management and the impact of the traffic flow load on the capacity have been demonstrated.

8. The obtained results of assessing traffic flow parameters are used for improving the efficiency and quality of activities undertaken by the state bodies, services and companies in the transport sector to support decision-making on:

- accounting and redistributing traffic flows within transport highways, street and road networks,
- analysing transport load,
- providing optimal traffic management,
- upgrading the available and designing new road networks.

9. Moreover, the introduced tool is employed for analysing transport corridors, the main highways and city streets to find sections primarily required for upgrading and improving.

REFERENCES

Blinkin, M. Ya., & Tkachenko, B. A. (2009). Sistemnaya otsenka usloviy dvizheniya na baze modeli Khermana-Prigozhina. Sotsial'no-ekonomiche-skie problemy razvitiya transportnykh sistem gorodov i zon ikh vliyaniya. In *Materialy XV Mezhdunarodnoy nauch.-prakt. konf.* (pp. 135–143). Yekaterinburg, 16–17 Jun. 2009. Yekaterinburg: Izd-vo ABM. (in Russian).

Daganzo, C. F. (1997). *Fundamentals of transportation and traffic operations* (Vol. 30). Oxford: Pergamon.

Dryu, D. (1972). *Teoriya transportnykh potokov i upravlenie imi*. Moscow: Transport. 424 p. (in Russian).

Gartner, N. H., Messer, C. J., & Rathi, A. (2002). *Traffic flow theory – a state-of-the-art report: revised monograph on traffic flow theory*.

Herman, R., & Prigogine, I. (1979). A two-fluid approach to town traffic. *Science*, *204*(4389), 148–151.
https://doi.org/10.1126/science.204.4389.148

Inose, Kh., & Khamada, T. (1983). *Upravlenie dorozhnym dvizheniem*. Moscow: Transport. 248 p. (in Russian).

Lighthill, M. J., & Whitham, G. B. (1955). On kinematic waves II. A theory of traffic flow on long crowded roads. *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*, *229*(1178), 317–345.
https://doi.org/10.1098/rspa.1955.0089

Lutts, M. (2010). *Izuchaem Python [Studying Python]*. Moscow: Simvol-Plius Publ. (in Russian).

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Mikhaylov, A. Yu., & Golovnykh, I. M. (2004). *Covremennye tendentsii proektirovaniya i rekonstruktsii ulichno-dorozhnykh setey gorodov*. (in Russian).

Nelson, P., & Sopasakis, A. (1998). The Prigogine-Herman kinetic model predicts widely scattered traffic flow data at high concentrations. *Transportation Research Part B: Methodological*, *32*(8), 589–604. https://doi.org/10.1016/S0191-2615(98)00020-4

Payne, H. J. (1971). Model of freeway traffic and control. *Mathematical Model of Public System*, 51–61.

Richards, P. I. (1956). Shock waves on the highway. *Operations Research*, *4*(1), 42–51. https://doi.org/10.1287/opre.4.1.42

Shvetsov, V. I. (2003). Matematicheskoe modelirovanie transportnykh potokov. *Avtomatika i Telemekhanika*, (11), 3–46. (in Russian).

Vrubel', Yu. A. (2003). *Poteri v dorozhnom dvizhenii*. Minsk: BNTU. 380 p. (in Russian).

Vrubel', Yu. A., Kapskiy, D. V., Rozhanskiy, D. V., Navoy, D. V., & Kot, E. N. (2011). *Koordinirovannoe upravlenie dorozhnym dvizheniem*. (in Russian).