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Road Management with Mathematical Accuracy

Larisa A. KARGINA

Larisa A. Kargina
Russian University of Transport, Moscow, Russia.
✉ *kargina_larissa@hotmail.com.*

ABSTRACT

Paraskevov, A. V. Improving road traffic management based on the use of mathematical and instrumental methods of economics [Sovershenstvovanie upravleniya dorozhnym dvizheniem na osnove ispolzovaniya matematicheskikh i intrumentalnykh metodov ekonomiki]. Moscow, Vologda, Infra-Inzheneriya publ., 2023, 84 p. ISBN 978-5-9729-1283-4.

The article is a review of the monograph «Improving traffic management based on the use of mathematical and instrumental methods of economics», written by A. V. Paraskevov, a senior lecturer at the Department of Computer Technologies and Systems of the Kuban State Agrarian University named after I. T. Trubilin and published by Infra-Inzheneriya [Infra-Engineering] publishing house. The work summarises and systematises extensive material on innovative methods for improving management of road traffic congestion levels. An also considered application for motorists is designed to build optimal routes taking into account the current situation on urban roads.

Keywords: traffic management, economic and mathematical methods.

Transport flow issues have been relevant for many decades – already in the 1950s, American researchers considered a probability of emergence of traffic congestion. In-depth research on the topic under consideration was carried out by such scientists as S. Drew, R. Donald, T. Metson, H. Inose, T. Hamada. They comprehensively studied aspects of traffic management, adding their own vision to the solution of the problem. Currently, traffic congestion is a global problem in large cities since in most cases they were built spontaneously, haphazardly, and during construction of roads there was no calculation of vehicles for the future. Indeed, now there are measures to combat traffic jams; the author of the monograph lists the main ones:

1. Operation of traffic lights in the «green wave» mode.
2. Organisation of traffic of heavy vehicles on bypass roads.
3. Construction of backup city roads.
4. Ensuring maximum visibility of road signs for drivers.
5. Organisation of maintenance work at night.
6. Improving the quality of the road surface.
7. Installation of additional traffic lights intended for those vehicles that turn.
8. Regulation of roads by introducing toll tariffs.

The monograph «Improving traffic management based on the use of mathematical and instrumental methods of economics» is devoted to solving the issue

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The text of the review article originally written in Russian is published in the first part of the issue.
Текст статьи-рецензии на русском языке публикуется в первой части данного выпуска.

of traffic regulation through introduction of road tolls, however, at the same time, the author notes the need for an integrated approach. The key position is that once the potential demand for travel is high enough to cause congestion, then the costs of travel will rise, causing the decrease in effective demand for travel, so the costs will be balanced, leading to equilibrium of queues on the transport network. The creation of substituting toll routes allows the driver to travel without traffic jams (i. e., loss of time), but this is not enough to keep the flow within the limits of road transit capacity (the number of cars that can pass through a specific section of the road per unit of time with a given speed and traffic safety).

The first part of the monograph examines in detail the history of development of road traffic using the example of the city of Krasnodar. The author provides an analysis (data based on observations of problem areas) of the time frame during which traffic is most congested, for example, the two most peak periods are morning and evening. Contrary to the seemingly obvious conclusion that traffic jams arise due to job schedule the author focuses on the fallacy of this judgment: the problem is really a combination of many factors and can be solved exclusively by a systematic approach and the introduction of a whole set of measures. For clarity, the monograph includes not only maps with the territorial division of the most problematic areas and residential areas of Krasnodar in terms of road traffic: the author divides, «breaks» them into graphs and subgraphs, on which traffic flows and possible routes are clearly visible. Problems and constraints indicate that the current state of road traffic can hardly be called satisfactory, and their presence in general causes the loss of possible profits by both the city, the state, and traffic participants. In addition, we are talking about the moral and environmental damage caused by poor distribution of road traffic; Research shows that frequent exposure to traffic jams can cause serious harm to human health. An acceptable urban environment is a complex concept that directly depends on customer satisfaction, the achievement of which in large cities is hardly possible: transit indicators will vary in settlements of over a million people and below one hundred thousand. The monograph presents various measures to reduce traffic jams in the city, taking into account the specifics of the city. Krasnodar does have a traffic management system, but the measures undertaken within its framework are not sufficient to ensure uninterrupted operation.

For uniform development and stable functioning of all infrastructure elements, as well as for increase in its efficiency, there is the need for introduction of high-quality, economically developed solutions. The introduction of tolls on certain sections of the road will result in drivers either looking for an alternative route or paying tolls.

The second part of the study is devoted to the current state of urban transport infrastructure. The author of the monograph offers his own methodology for improving traffic management based on classification into two components – clustering and explanatory ones. Such modelling and introduction of tariffs might result in a significant reduction in traffic jams due to «replacement» of lost time with an equivalent fee. The technique itself includes five stages:

1. Definition of variables for road segments.
2. Generation of clusters of segments within the road network.
3. Classification of all segments of the road network into clusters.
4. Assigning a load level category to each cluster.
5. Scaling the cluster approach throughout the entire city infrastructure.

The top level of analysis consists of collecting information about the level of traffic congestion; it depends mainly on the data of geographic information systems – it is from them that a set of segments and intersections is subsequently constructed; they become variables for clustering components. Congestion factors are eight variables: roadway width, number of traffic lanes, presence of bicycle infrastructure, presence of cargo vehicles, average traffic speed, smoothness of flow, congestion, size of traffic flow (the author provides formulas for their calculation). Then it is necessary to perform clustering with a representative subset of the network to identify segments with similar characteristics. Based on the results of segment classification, the probability of the formed segment belonging to a specific cluster is established. Subsequently, the cluster is assigned a category of traffic congestion level (an important aspect is considering the context and statistics of a particular location).

The undoubted advantage of the monograph is the large amount of illustrative material: the work contains a sufficient number of maps, diagrams, and graphs. Thus, the methodology is presented schematically for its greatest understanding, and the variables are presented in tabular form.

Cluster analysis is of greatest interest. Its key goal is to find groupings of road segments based on the above variables. The main characteristic of segments within clusters is their similarity to each other, but their difference from the components of other clusters. The first step of cluster analysis is normalisation of road segment variables (the author suggests using the scoring method to transform continuous variables). Next, it is necessary to create a proximity matrix that determines the degree of similarity between road segments. The technique uses the «K-medoids» algorithm, which assigns all considered elements using partitioning – one of the most reliable algorithms that works with continuous and discrete variables. Calculating the average checks the correctness of classification within clusters, so the highest values indicate the correctness of the previously performed actions. The optimal number of clusters may vary.

The monograph discusses important aspects of the proposed methodology. Given the large number of segments of the road network, scaling is required (the ability to work under heavy load). The technique allows not only to scale the model, but also to predict the impact of fluctuations in variables on classification of congestion levels of a particular segment. The way to interpret clusters was studied by considering the level of traffic congestion through analysis of indicators.

In addition, the author considers international experience in traffic management. Based on a large amount of collected information, confirmation of validity of the proposed methodology was obtained.

The final section of the monograph provides an overview of organisational and economic-mathematical methods for solving the problem under consideration. First, the demand for each «departure-arrival» segment is described – it is a function of the total costs of the trip. A capacity constraint equation is also introduced, which takes into account the demand constraint, the constraint to preserve the flow within the transport network, the capacity constraint and the condition of non-negativity of the transport flow.

To implement the proposed model, appropriate software operating in real time is required. Thus, the author of the monograph defines a list of requirements for it:

1. Determining the maximum response time of the system and ensuring the reaction.

2. Determining the priority of processed tasks.

3. Multitasking, allowing switching between tasks if needed.

4. Continuous operation for a long time.

The user interface must also meet a number of requirements in order to be as easy to use as possible:

1. Ease of use by the driver (subtle colours, non-distracting animation, intuitive interface, voice control).

2. Similarity to the interface of other navigator applications for the most convenient user orientation.

The main difference of the application proposed by the author is calculation of the maximum limit of cars for each street in real time: thus, the navigator will offer the driver the optimal route. The construction of the route is based on three indicators in accordance with their priority: first, the forecast travel time, secondly, the level of traffic congestion at the current moment, and thirdly, achievement of the permissible congestion limit. In this case, traffic jams and time tend to a minimum, and traffic congestion reaches its optimal value. Of course, such an application requires data collection to function properly. The author of the monograph lists the necessary sources, including current city and traffic maps, information about current maintenance and possible repair work, the number of cars on the roads, cameras, and traffic signs. The author assumes that in the future the application will directly influence the city's road system by distributing the load between city streets. The work simulates the interaction of a potential user with the application, describes in detail an example of constructing a route, and compares it with the proposed Yandex.Navigator.

In addition, to illustrate the effectiveness of the implemented model, a graph of speed changes along the routes under consideration was constructed using the example of the city of Krasnodar. When comparing them, it becomes obvious that the intuitive route, as well as the one proposed by the navigator, is not optimal in terms of time spent on the road. The advantage is not only the unloading of roads, but also the ability to predict time, which is an important advantage, because time is the most important resource that every person tries to minimise.

The congestion management service application proposed by the author is intended not only to qualitatively improve the traffic situation on the roads, increase driving safety and significantly reduce the time spent by drivers. It is important to note that the methodology will help to identify the weak points of urban infrastructure and analyse the impact of its new elements on traffic dynamics.

The monograph is a completed scientific work that proposes an up-to-date methodology for regulating traffic. The methodology is considered using the example of Krasnodar. the issue of scaling the method to other cities is debatable; it would be worthwhile to dwell in more detail on the algorithm for preparing for data collection when introducing the method in other cities. It is necessary to have answers to several questions. «What should be the starting point for implementation, what problems can signal problems with traffic? Is it possible to implement the technique on specific sections of the road or it is strictly advisable to apply it on a city scale?» However, the proposed methodology can indeed be applied in other regions. The author describes in detail both the internal operation of the application and the user's interface; one might say, a full-fledged technical specification has been prepared for further development.

The monograph «Improving traffic management based on the use of mathematical and instrumental methods of economics» is characterised by scientific novelty and practical value: the author's new approach can really be applied to solve the problems of traffic congestion. ●

Information about the author:

Kargina, Larisa A., *D.Sc. (Economics), Head of the Department of Information Systems of the Digital Economy, Professor of Russian University of Transport, Moscow, Russia, kargina_larissa@hotmail.com.*

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