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Promising Areas of Research for Developing Single Approaches to Assessing the Quality, Dependability and Efficiency of Traffic Management

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ABSTRACT

The article provides proposals for improving the efficiency of traffic management using geoinformation data. The objective of the research is to identify promising areas of research to develop single approaches to assessing quality, dependability, and efficiency of traffic management using relevant criteria.

The authors reviewed these criteria from the point of view of regulatory documentation and noted the possibility of using models of urban road networks to find optimal modes of managing traffic at minimal cost. Since previous studies showed the lack of single approaches and clear criteria for optimising traffic management, it was proposed to comprehensively consider the possibility of assessing traffic not only from a technical point of view, but also from the point of view of approaches used in management theory.

As a tool of assessment of the efficiency indicators of traffic management, a time cost function was proposed, which is the sum of the time costs for all the road users. Increasing the efficiency of traffic management is achieved by minimising this function. It is also noted that when the time cost function is reduced, the material costs of road users, such as fuel costs, are reduced.

Having examined the principles of functioning of road traffic in other countries, the authors identified two approaches to management of traffic on the road network: mechanistic and organic ones. Mechanistic approach presupposes strict respect of the rules by all the road users, while organic one presupposes the ability to deviate from the rules. The authors presented examples of self-organisation of traffic on sections of the road network of the city of Irkutsk, which is an example of application of an organic approach to organising traffic in Russia.

The article results in development of several promising areas of research, due to which uniformity of approaches to selection and formation of requirements for indicators of depedability, quality and efficiency of traffic management can be achieved.

Keywords: transport, street and road network, traffic management, geographic information systems, dependability, quality, efficiency.

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INTRODUCTION

The growing motorisation poses a serious challenge to the existing street and road network (hereinafter referred to as SRN). Traffic congestion occurs every day in many cities, especially often during morning and evening rush hours. Many researchers have been studying the processes of occurrence and assessment of congestion for a long time [1–11], however, the organisation of traffic on such road networks is problematic if outdated approaches are used.

Modern software solutions that allow modelling of traffic flows on urban SRN in conjunction with existing digital maps of geographic information systems (hereinafter referred to as GIS), can optimise the process of increasing the efficiency of traffic management (hereinafter referred to as TM) in the cities.

To organise such work, a one-time transfer of existing digital GIS maps into a traffic modelling program is sufficient. Next, it is necessary to perform the following algorithm of actions:

• To enter information about the operating modes of traffic light systems and other information about the parameters and operating modes of SRN.

• To collect data on existing traffic volumes on SRN.

• To refine (adjust) the model to real conditions, that is, to correct errors that could arise during data transfer.

Combining all the information in a single model will make it possible to simulate the operation of the city's traffic system during different periods of the day, and this, in turn, will make it possible to optimise the operation of the city's traffic system, select optimal operating modes for traffic lights, and develop recommendations for changing traffic patterns.

Any changes to TM scheme planned by local governments can be assessed at the planning stage.

The implementation of such an approach is possible at the state level by creating a single TM centre that might carry out similar work for all settlements of the country. The creation of such centres in every city or region is impractical, since operation of such centres requires highly qualified specialists, and the services of such a centre are not constantly required in cities, that is, many cities can be provided by a single centre.

However, to optimise the operation of the TM system, it is necessary to determine criteria for evaluating its operation and select optimisation criteria.

In general, the criteria by which TM is assessed can be divided into three groups:

• Dependability criteria.

• Quality criteria.

• Performance criteria.

Thus, the *objective* of the research is to determine promising directions for further development of single approaches to assessment of quality, dependability, and efficiency of traffic management in accordance with relevant criteria.

Each of the groups of criteria is independent and allows assessing TM under different aspects; nevertheless, further research can result in determining integral criteria of TM assessment that consider the above parameters.

RESULTS

Since SRN is a technical item, it is subject to GOST [State Standard] R 27.102–2021 «Dependability in Technics» [1,2], where dependability means a property of an item to maintain over time, within established limits, the values of all parameters characterising the ability of an item to perform the required functions under the given modes, conditions of use, maintenance, storage, and transportation strategies.

In accordance with this GOST, dependability is a complex property, which, depending on the purpose of the item and the conditions of its use, may include:

• Reliability: the property of an item to continuously maintain an operational state for some time or operating time in specified modes and conditions of use.

• Durability: the property of an item to maintain an operational state until a limit state occurs with an established maintenance and repair system.

• Maintainability: a property of an item, which consists in its adaptability to maintaining and restoring the operability of the item through maintenance and repair.

• Availability: the property of an item to maintain, within specified limits, the values of parameters characterising the ability of an item to perform the required functions during and after storage and (or) transportation.

[1] GOST R 27/102–2021. Dependability in technics. Dependability of item. Terms and definitions. [Electronic resource]: https://docs.cntd.ru/document/1200181141. Last accessed 23.06.2023.

[2] Developed taking into account main provisions of the IEC standard 60050–192:2015 «International Electrotechnical Vocabulary – Part 192: Dependability», NEQ. – *Ed. note.*

Quality, according to GOST [State Standard] R ISO 9000, means the degree of compliance of inherent characteristics with requirements[3,4]. The term «quality» has a broader interpretation and can include not only technical requirements, but also user requirements for functioning of SRN. Efficiency indicators, presented as the ratio of the result obtained to the costs incurred, are best assessed through time and monetary (material) costs [12].

Since the main task of SRN is to enable vehicles to move, the result is the vehicle's arrival at its destination. Thus, the result is constant, while the time and material costs may vary. In case we are talking about functioning of SRN, then it all comes down to optimising the function $F(t) = \sum t_i$, where t_i is the time spent on movement by road users. It is logical to assume that if the function is optimised, the material costs incurred by road users, such as fuel costs and vehicle wear and tear, can also be optimised. In addition, reducing travel time increases the productivity of organisations involved in passenger and cargo transportation.

Some approaches to estimating the efficiency through monetary costs borne by road users have been presented previously in [12].

It is worth understanding that the function $F(t)$ tends to a certain limit due to existing speed limits, a possibility of losing time when passing intersections, pedestrian crossings, humps and traffic lights and due to other factors. In addition, increasing the number of traffic lanes is not always possible, and when such an opportunity exists, multiple increases may not be practical.

Increasing the number of lanes by widening the roadway, constructing bypass routes, or making other changes to the configuration of the road network requires investment of funds, the volume of which is limited. In this regard, it is necessary to determine the assessment of time parameters to be able to compare them with financial costs of reconstructing the roadway.

This largely affects moral aspects in terms of assessing the cost of a person's lifetime, however, such a comparison might be necessary to select the most effective option for optimising (modernising) the SRN operation.

In the simplest version, when choosing possible alternatives for spending funds, it is possible to directly compare the reduction in time costs ($\Delta F(t)$) with the cost of various available options for reconstructing SRN. In this case, the option or options with the highest specific time savings can be selected.

Besides, if the approach to creating a single TM centre is implemented at all SRN, first, measures should be taken to assess the efficiency of traffic light facilities and options for optimising their operation should be proposed, since reconfiguring traffic light facilities requires a minimum amount of investment.

As described earlier, in addition to time losses, material losses should also be assessed.

After determining the assessment criteria, it is also necessary to resolve the issue of collecting data on traffic parameters. As noted in previous studies [13], data collection can be carried out both using single sources of GIS data, such as vehicle-mounted laboratories, and using mass sources of GIS data. The collection of GIS data can be also performed using previously suggested methods [14]. The effectiveness of using certain data sources for each of the indicators used should also be assessed.

Management theory suggests two approaches to creation of management structures: mechanistic and organic ones [15]. The organisation of traffic on urban road networks is implemented in varying degree using these approaches. The first approach assumes full compliance with traffic rules (hereinafter referred to as TR) by road users. This approach is good because road users know in advance the behaviour of others. The creation of potential emergency situations is unlikely. However, this approach requires a larger amount of work on TM, both from the point of view of creating road infrastructure, for example, installing additional, duplicate signs, traffic lights and taking other measures, and from the point of view of monitoring violations. Understanding by road users of inevitability of punishment and that violation of the rules will reduce the quality of traffic for themselves and others, as well as the extremely low number of cases in which drivers could interpret the situation on the road in two ways, leads to the fact that an understanding of the need to strictly follow traffic rules is formed at the institutional level and is intuitive. This

[3] GOST R ISO 9000. Quality management systems. Fundamentals and vocabulary. [Electronic resource]: https://rustestm.ru/wp-content/uploads/2021/10/gost-r-iso-9000–2015-sistemy-menedzhmenta-kachestva-osnovnye-polozheniya-i-slovar.pdf. Last accessed 23.06.2023.

[4] Identical to ISO 9000:2015 «Quality management systems – Fundamentals and vocabulary», IDT. – *Ed. note.*

approach, in our opinion, is found in European countries, for example, in Germany.

The organic approach presupposes the presence of some unspoken rules (concepts) that have developed among road users in general, or when driving on certain sections of SRN. In this case, traffic rules are necessary only to give a general concept of road traffic and determine the culprit in case of an accident.

With the organic approach, the main criterion for movement is reasonable behaviour and minimisation of the cost function. That is, if it is possible to violate traffic rules without consequences or with minimal risk of receiving a fine, then they will be violated if this leads to a «win» for the road user. The behaviour of road users can be described using approaches based on the game theory.

For example, with an organic approach, suddenly changing lanes in front of another car is considered normal, since road users realise that all road users are not interested in an accident, as a lot of time will be spent on processing it, the innocent participant in the accident will incur additional transaction costs associated with receiving compensation from the insurance company, or through the court, if the liability of the person responsible for the accident was not insured. Also, a car after an accident is usually sold at a discount compared to an undamaged one. In addition, the driver of the car whose lane the offender is entering can be recognised as the culprit of the accident if there will be nit a side collision, but a collision with the rear of the offender's car, and of in the absence of other objective data (video recorders, surveillance cameras, witness statements, etc.) etc.) the culprit of the accident will insist that there was no lane-changing manoeuvre, and the driver of the second car did not keep his distance. Thus, as a rule, an accident is not beneficial to any of the participants in the accident, and often it is easier for the driver to give way to the offender rather than incur time and material costs.

With the organic approach, traffic participants (government authorities) often unconsciously use the approach of reducing the time cost function $F(t)= \sum ti$ associated with all road users, that is, the system comes to equilibrium. The possibility of the existence of equilibrium in such systems was proven earlier [16].

Thus, at the institutional level, the main priority for road users is formed, which is to avoid colliding with the cars of other traffic participants. The combination of mechanistic and organic approaches requires less government control and less investment in road infrastructure since self-organisation of the road traffic system is carried out in some sections of the road network. This approach is being used in some Asian countries.

However, in some cases, a similar approach, in our opinion, is also applied in Russia.

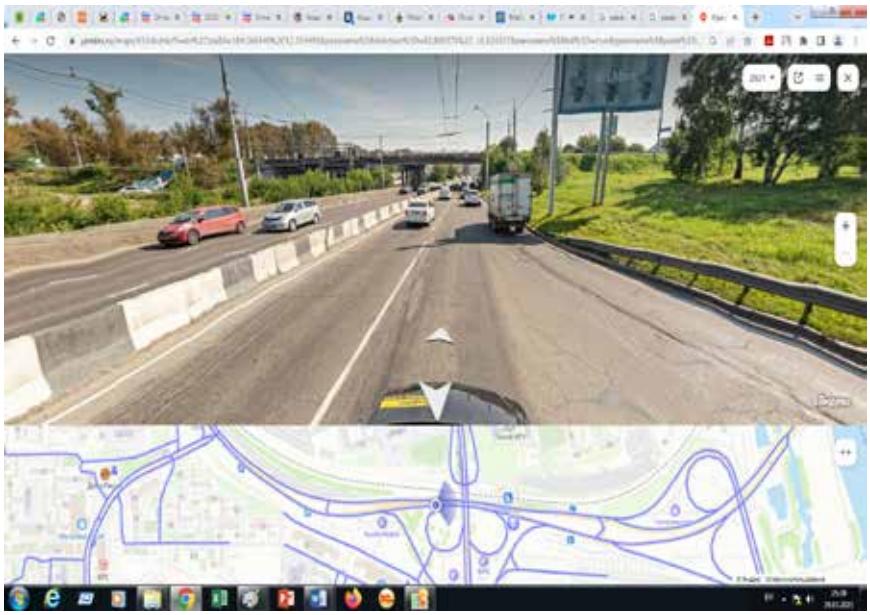
For example, in the city of Irkutsk during rush hours, exiting from a two-level interchange on Lermontov Street (Pics. 1, 2) respecting traffic rules is impossible due to the high traffic intensity on the bypass road; a similar situation arises when passing the road section of Gornaya street – K. Liebknecht street – I. Utkin street (Pics. 3, 4).

During peak hours, to be able to exit a secondary road in accordance with traffic regulations, in these examples it is necessary to install traffic lights. Nevertheless, due to the understanding that, despite the priority of traffic, it is necessary to give way to cars moving from the secondary road to avoid colossal congestion on the adjacent streets, traffic participants use an organic approach. By periodically giving way to cars that do not have priority, self-regulation of movement occurs and the social function of time costs $F(t)= \sum t_i$ decreases. If traffic rules were fully observed during peak hours, a traffic jam would occur, the length of which would exceed the length of the road segment, that is, the traffic jam would restrict traffic at other intersections.

The disadvantage of the mechanistic approach is the fact that in case of a malfunction of traffic management systems, for example, disruption of operation of a traffic light facility, the absence of a road sign or incorrect markings, road users will either be unable to continue moving or traffic conditions will be significantly worsened. Besides, not all the situations are specified in the traffic rules, and they could not be applied at all sections of the road traffic system, especially in old urban areas. The disadvantage of the organic approach is that the lack of clearly defined requirements can lead to the phenomenon that different road users may have different priorities and, accordingly, there may be a misunderstanding of the events taking place.

In general, considering both approaches, it can be noted that both approaches have pros and cons, and for optimal traffic management, a combination of both approaches can be used to achieve reliable, high-quality, and efficient functioning of SRN.

Pic.1. Scheme of a two-level interchange on Lermontov Street (Irkutsk) [image from the website 2GIS https://2gis.ru/irkutsk].



Pic. 2. Exit from the two-level interchange on Lermontov Street (Irkutsk) [image from the website Yandex.Maps https://yandex.ru/maps/63/irkutsk].

CONCLUSIONS

The choice of regulatory instruments using a mechanistic or/and organic approach is an important condition for reliable, high-quality, and effective TM. For correct selection of control and management actions, it is necessary to determine the criteria for assessing TM. Such an assessment can be carried out based on indicators of dependability, quality, and efficiency of SRN.

Both in regulations and research sources there are different approaches to determining road traffic parameters, however, there is no clearly developed methodology and uniformity of approaches to selection and formation of requirements for indicators of dependability, quality, and efficiency

Pic. 3. Route Gornaya street – K. Liebknecht street – I. Utkin street (Irkutsk) [image from the website 2GIS https://2gis.ru/irkutsk].

Pic. 4. Exit from Gornaya street on K. Liebknecht street (Irkutsk) [image from the Yandex. Maps website https://yandex.ru/maps/63/irkutsk].

of TM. Thus, the research conducted has shown that the following areas of research are promising:

1. Classification of indicators, and the selection of the most relevant indicators for assessment of TM's dependability, quality, and efficiency.

2. Scientific justification for applicability of those indicators. depending on the parameters of the street and road network, as well as evaluation of possibility of application of integral criteria for TM assessment.

3. Scientifically based standardisation of these indicators depending on the length of the SRN and other parameters.

4. Scientifically based choice of sources of data on parameters of SRN operation, assessment

of optimal frequency of data collection for measuring each of the indicators.

5. Development of scientifically grounded approaches to modelling of traffic flows when monitoring road traffic and scientific substantiation of the requirements for models used for monitoring.

6. Development of research methods for economic assessment of losses caused by congestion, depending on the considered indicators of SRN operation.

Conducting research in these areas will improve theoretical knowledge in this field and will significantly increase the efficiency of road traffic monitoring.

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