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Methodology for the Formation of the Infrastructure of Intelligent Management of Transport Processes

Mikheeva T.I.*
Samara National Research University named after academician S.P. Koroleva,
Samara State Technical University,
IntelTrans Group of Companies
Samara, Russia
Mikheevati@gmail.com

Mikheev S.V.
Samara National Research University named after academician S.P. Koroleva,
IntelTrans Group of Companies
Samara, Russia
Mikheevati@gmail.com

Chugunov A.I.
Samara National Research University named after academician S.P. Koroleva,
IntelTrans Group of Companies
Samara, Russia
Mikheevati@gmail.com

***Abstract*—The article discusses the methodology of a system analysis of the formation of the infrastructure of intelligent management of transport processes with the scientific substantiation of strategic decisions in the intelligent transport geographic information system ITSGIS. A serious problem is the creation of integrated automated control systems, both for the entire transport infrastructure of the urbanized territory, which includes a street-road network, technical means for organizing traffic, traffic flows, and its individual facilities. Fundamentally new approaches are required to create integrated systems that simultaneously cover arrays of heterogeneous data and provide multi-level interaction of many subordinate complex subsystems, the construction of urban high-speed roads, the development of traffic flow management methods, including the use of intelligent transport systems. As a structural-parametric model problem, the problem of network-centric management of transport infrastructure (objects and processes) is implemented in the development of methods for managing transport objects and processes and the methods of conducting a simulation experiment as part of a designed decision support system for managing transport infrastructure in local areas of coordinated management. The described intellectual transport geographic information system "ITSGIS" is distinguished by the availability of developed means of supporting the simulation environment, which provide ease of modification and expansion of the range of research tasks based on patterns and neural networks. Within the framework of network-centric management, the tasks of stratified zonal control of transport processes have been solved: local control at the stage and intersection, coordinated management on highways with the development of control actions for various types of zoning of transport infrastructure. For large areas, from the point of view of the territory of the management area, coordinated management is divided into tasks of dividing the area into special zones and the operational formation of coordination programs for each of them, synchronization of coordination programs (provided that the control cycles are equal or multiple). The tasks of system management of objects and processes of the transport infrastructure are interconnected.**

Keywords—Intelligent transport geographic information system, "ITSGIS", infrastructure, network–centric management, strategic management solutions

I. Introduction

The successes of the automotive industry of recent decades, which led to the "explosive growth" of the Russian car fleet, are significantly ahead of the pace of road construction, and therefore, increasingly high demands are placed on the quality of designing street–road networks (UDS) and organization road traffic. In this regard, the creation of integrated automated control systems poses a serious problem, both for the entire transport infrastructure of the urbanized territory, which includes a street–road network, technical means of organizing road traffic, traffic flows, and its separate facilities. Fundamentally new approaches to the creation of such integrated systems are required, simultaneously covering arrays of heterogeneous data and providing multi–level interaction of many subordinate complex subsystems, the construction of urban highways, the development of traffic flow management methods, including the use of intelligent transport systems [1-3].

The creation of integrated intelligent transport systems (ITS), as a control system for road transport infrastructure, will increase the level of traffic management: improve the characteristics of the road network, improve the deployment of traffic management equipment, optimize the process of traffic management tailor flows in all phases of movement, reducing transport delays, increasing traffic safety.

The work considers a system analysis of the formation of the infrastructure of intelligent control of transport processes with the scientific substantiation of strategic decisions [4-6]. An analysis of Russian and foreign experience in the design and development of ITS, the principles of their integration, use in the implementation of freight and passenger traffic, in the management of traffic flows in various transport situations in the event of an accident, allows us to conclude the feasibility of using ITS in automobile transport.

II. Development of Methodological Support in the Field of ITS

The developed multi–level, complex–organized ITS is a hybrid system consisting of many heterogeneous systems that interact in a complex way – managing, classifying, forecasting, expert, making decisions or supporting these processes, combined to achieve a single goals, with visualization and deployment of objects of transport infrastructure on the thematic layers of an interactive electronic map in the intelligent transport geographic information system ITSGIS («ITSGIS») [7].

Intelligent transport system is a classic example of a complex system with its inherent properties [8-9]:

- multidimensionality and hierarchy of the system, due to a large number of interrelated elements;
- system emergence;
- multifunctionality of system elements;
- multicriteria, determined by immanence (mismatch) of the goals of individual elements of the system;
- complex (probabilistic and dynamic) behavior, manifested in the interconnection of subsystems and requiring feedback when controlling;
- complexity of information processes;
- the need for high automation control.

From the standpoint of the structural–functional approach, ITS can be defined as the unity of structure, functions and integrity. The structure characterizes the elements of ITS and their interaction. Functions determine the nature of the relationships between elements and the behavior of ITS. Integrity expresses the interdependence of the structure, functions and goals of ITS and is manifested in the presence of a number of new ones in the real system, i.e. emergent properties that are not inherent in its individual elements, and cannot be deduced from the properties of these elements, and methods of their connection.

An attempt to create an infrastructure of intellectual management of transport processes with the scientific substantiation of strategic decisions based on ITS was implemented by the creation of the Center for Organization of Traffic. The center acts as a coordinator for a series of activities related to the implementation of activities:

- preparation of draft laws and regulations within the jurisdiction of the City Administration, methodological support for the creation of a safe and effective traffic management system, traffic management and parking;
- monitoring compliance with laws and regulations developed by the Department of Organization of Road Traffic at the federal and regional levels;
- coordination of the development and implementation of strategies, plans, measures to ensure the organization of traffic;
- consideration and approval of projects and traffic management schemes;
- introduction of modern innovative technologies and methods of traffic management: intelligent transport systems, automated traffic control systems [10];
- consideration and approval of projects for the construction of roads and streets, approval of construction dates, conclusion of contracts for construction work related to measures for the organization and safety of traffic, the appointment of examinations of construction projects and reconstruction of the road network, routes and passenger traffic patterns, projects for all types of outdoor advertising, etc., developed by other organizations and affecting traffic conditions;
- participation in the work of town–planning and technical councils, commissions for the commissioning of roads, road structures, railway crossings, technical means of organizing road traffic and other objects;
- control over the implementation of work on the organization of road traffic, in accordance with applicable standards, tariffs, rules and approved design estimates;
- preparation and execution of administrative and technical documentation for closing the traffic of the trans–port on road sections during their construction, reconstruction and repair; consideration and approval of proposals for the temporary restriction or prohibition of traffic;
- monitoring and collecting data on road traffic, analysis of monitoring results, evaluation of traffic management schemes and strategies, the capacity of the road network, development of recommendations for improving the efficiency and safety of road traffic;
- organization of information, routing and orientation of the participants in the movement;
- analysis of the causes of foci of traffic accidents and preparation of proposals for their elimination;
- implementation of measures to increase the attractiveness and efficiency of public transport with the priority of public transport;
- development of a concept for the development of street and public off–street parking, including their location on the map in ITSGIS, the number of parking spaces, the tariff policy with the parking standards for use in residential and non–residential areas, monitoring compliance with accepted standards and organization of car parking.

III. SYSTEM ANALYSIS, CLASSIFICATION OF ITSGIS TASKS

The classification of problems solved within the framework of the functioning of the transport infrastructure determines the strategy and tactics of the synthesis of intelligent transport geoinformation systems.

1. Tasks of monitoring

1.1. Traffic monitoring [11,12]:

- monitoring the characteristics of traffic flows (speed, intensity, density, composition, etc.);
- collection of data on traffic conditions using control vehicles;
- traffic control on expressways.

1.2. Monitoring the performance of the road network:

- certification of roads, multilevel transport interchanges and tunnels;

- certification of elevated and underground pedestrian crossings;
- certification of railway crossings;
- assessment of the current condition of roads;
- emergency recovery monitoring.

1.3. Monitoring traffic management equipment

- register of technical means of traffic management (road signs, traffic lights, road markings, etc.);
- runk and network control of traffic light signaling;
- automatic electronic fare and parking.

1.4. Environmental pollution monitoring.

2. Management tasks

2.1. Traffic management [13]:

- coordinated management of transport flows;
- quality assessment of the functioning of the transport network;
- emergency traffic management;
- traffic accident detection;
- monitoring congestion situations to assess the dynamics of their development;
- development of a traffic management strategy in a congestion situation;
- traffic management systems integration;

2.2. Transportation Management

- providing pre–transport information, informing clients about the route network, travel planning;
- booking transport services;
- estimation of demand for transportation;
- route orientation, on–line monitoring of the route;
- development of management strategies in specific situations;
- operational change of traffic management schemes;
- priority traffic management of route vehicles;
- route navigation and giving priority to special single and convoys of vehicles;
- monitoring the transportation of dangerous and bulky goods;
- route network optimization;
- integration of transportation management systems;

3. Tasks of information support for the participants in the movement

- information transfer through communication channels;
- segmentation of information flows;
- integration of database management systems on road traffic.

4. Tasks for visualization of geo–objects of transport infrastructure [14]

- development of thematic layers of an interactive electronic map;
- visualization of the complex deployment of geo objects (roads, sidewalks, technical means of organizing traffic, etc.);
- expert analysis of the complex deployment of geo–objects;
- modeling of transport processes with the integration of control methods.

The analysis of ITSGIS shows that the concept of its functioning is to implement the functions of traffic and transportation management, to assess the degree of influence of various plug–ins on the development of transport infrastructure, to create the architecture of a transport infrastructure management system and to coordinate standards for the development of ITSGIS, as integrated systems. ITSGIS technologies currently have more than 40 applications, however, due to the immanence of the goals of each ITSGIS plugin individually, its potential capabilities, as a system unit, are realized by a specialized functional solution.

The synergistic effect in the design of ITSGIS is manifested in the form of an organizationally determined transition from immanence to synergy due to expanded system and functional integration (see figure):

- statement of the problems of the organization of transportation and movement;
- development of the concept of functioning;
- ensuring functional, institutional, informational integration;
- development of plugins of each functional group;
- integration of information technology;
- integration of information flows between plug–ins.

The level of systemicity is the higher, the higher the intensity of interaction of the ITSGIS plug–ins with each other, the more different are the properties of the system from the properties of its elements.

The functional integration of ITSGIS is ensured by the completeness and effectiveness of the collection, processing and transmission of real–time information about the characteristics of traffic flows, traffic accidents, traffic jams, public and freight transport traffic, etc.

Temporary integration is due to the need for prompt decision–making in the process of traffic management, development and implementation of control actions in real time.

Institutional integration is necessary to reconcile the interests of private firms, municipal authorities, and government, which, in an attempt to preserve their interests, restrict access to ITSGIS information.

Current trends in the development of ITSGIS show that one of the main goals of their functioning is to provide multimodal information not only to management structures, but also directly to participants in the movement. One of the most intensively developing directions of ITSGIS is marching navigation. The expanded navigation concept in ITSGIS provides for the obligatory performance of such functions as on–line monitoring of traffic flows and quality indicators of the functioning of the road network, dynamic choice of the driving route and information support for drivers when passing the route.

The latest achievements in the field of information technology, computer technology, modern communications, efficient navigation systems, technical means of collecting, processing information and regulating traffic are widely used in ITSGIS in traffic management and road transport due to the developed and implemented scientific knowledge for use of the full range of functional capabilities of these developments.

The development and development of methods, models, algorithms and software for the comprehensive solution of the problems of managing transport infrastructure, optimizing the management of traffic flows in an urbanized area under the application of ITSGIS is being implemented. The integration of heterogeneous information models of the transport infrastructure management system is carried out on the basis of a formal apparatus for the formation of knowledge about the subject area, based on the concept of an object–oriented approach.

The network–centric model of the transport infrastructure management system in ITSGIS is based on the principles of object distribution and control zoning. The network–centric management model is the basis of a decision support system for network–centric management of objects, zones and the transport infrastructure itself – a model of formalized synthesis of network–centric management. The semantics of the properties of the network–centric model: self–organization, openness, weak hierarchy in the decision–making circuit and the ability to generate goals within oneself, multi–agentism. Models of objects of transport infrastructure interact in a single information space. The network–centric principle of management is the construction of control zones intended for making management decisions and exchanging information between zone control centers.

Network–centric control model for vehicle traffic at regulated intersections based on source data monitoring:

$$f(t)=\begin{cases}0, & if \quad t<t_{\min},\\ \alpha\lambda e^{-\lambda(t-t_{\min})}, & if \quad t\geq t_{\min},\end{cases} \tag{1}$$

where $f(t)$ – density distribution of intervals in the transport stream;

α – the proportion of the free part of the traffic flow, defined as $\alpha=1-\theta$,

θ – share of cars in groups;

λ – distribution parameter;

$t_{\min}$ – minimum interval between vehicles in the main flow, s;

λ – interval allocation parameter in the main transport stream;

$$\lambda=\frac{(1-\theta)I_p}{1-t_{\min}I_p}=\frac{\alpha I_p}{1-t_{\min}I_p} \tag{2}$$

where I_p – traffic intensity in the main direction of the roadway, car/s;

$$\alpha=e^{-\beta I_p}; \tag{3}$$

where β – a parameter determined experimentally and having values from 6 to 9.

Throughput

$$Q_e=\frac{3600(1-\theta)I_p e^{-\lambda(t_c-t_{\min})}}{1-e^{-\lambda t_f}}=\frac{3600\ \alpha I_p e^{-\lambda(t_c-t_{\min})}}{1-e^{-\lambda t_f}} \tag{4}$$

where Q_e – minor transit capacity at the intersection, car/h ;

t_c – critical interval, s;

t_f – minor flow queue interval, s.

Critical interval – the minimum interval in the flow of the carriageway, at which it is possible to enter the ring from a secondary direction t_c – 4,8 s.

According to the simulation results, the intersection throughput is quite high and can be used with a total traffic intensity of up to 2100 – 2300 auth / h. In the indicated range of intensity, unregulated intersections have the best indicators of total traffic capacity and total delays, only if one of the streets in the intersection accounts for more than 80% of the total traffic.

IV. Conclusion

As a structural–parametric model problem, the task of network–centric management of transport infrastructure (objects and processes) is implemented in the development of methods for managing transport objects and processes and the methods of conducting a simulation experiment as part of a designed decision support system for managing transport infrastructure in local areas of coordinated management. The described intelligent transport geographic information system "ITSGIS" is distinguished by the presence of developed means of supporting the simulation environment, providing ease of modification and expansion of the range of research tasks based on patterns, neural networks.

Within the framework of network–centric management, the tasks of stratified zonal control of transport processes have been solved: local control on the stage and intersection, coordinated management on highways with the development of control actions for various types of zoning of the transport infrastructure. For large areas, in terms of the area of the management district, coordinated management is divided into tasks:

- division of the district into special zones and the operational formation of coordination programs for each of them;
- synchronization of coordination programs (subject to equality or multiplicity of control cycles).

The tasks of system management of objects and processes of the transport infrastructure are interconnected.

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