Justification of logistical approach application in road safety management

A S Afanas’ev¹, A M Egoshin², S V Alekseev²

¹Saint-Petersburg Mining University, 21 Line, St. Petersburg, Russia, 199106
² Military Academy of Logistics named after Army General A. V. Khrulyov, St. Petersburg, Russia, 199034

E-mail: al-ego@yandex.ru

Abstract. Application of systemic approach as implemented in logistics allows attaining an economic effect. Using logistics as a traffic management and safety-ensuring tool allows representing road traffic as a unified flow accompanied with other flows. It allows justifying adaptive control of traffic and road building and reconstruction processes for attaining a common goal: timely and exhaustive provision of road carrying capacity.

1. Introduction
Currently, the theory and practice of traffic organization uses an approach where each process or each road section and each road industry enterprise are regarded as independent units with their own goals, tasks and possibilities, ready to perform individual tasks allotted to it. It is assumed, that performance of individual tasks on behalf of each unit in total will correspond to solving global issues in traffic control and safety.

At that, information model of road traffic control and road safety is a succession of links consisting of controlling inputs affecting road traffic objects, which are considered individually, without any considerations for interrelation and mutual dependency of elements.

Information model of traffic control and road safety in city streets and on intercity roads with considerations for characteristics of traffic flow is a description of response generated by the traffic flow or its elements to a control input coming from technical means constituting the road traffic control system. An exact composition of road traffic control technical means depends on selection of a traffic control information system.

The information model is selected from the road traffic control system function on the road network and requirements imposed by traffic control authorities. It is practical to apply a general problem of synthesis of automatic control system [1, 2, 3] to development of traffic control information system.

2. Materials and methods
For a long time, logistics has already been using transport as an object of logistical transformation of economic processes linked to profit winning for business [4, 5]. However, applying logistics as a systemic approach to system and process organization to ensure functioning of the transport itself has not been used as widely.
What differs the logistical approach from previously employed control of material resources is that its object is a flow: a set of objects considered as an integral whole. This is of importance for road traffic as well, which is a set of transport flows, as well as information, financial, resource and other associated flows [5]. When selecting the model of coordinated control, formalization covers the properties of the controlled object (transport flow and associated flows), operating conditions of the transport flow – destabilizing factors – road – environment – drivers system; requirements of the traffic control authorities to a traffic control system (TCS).

3. Results and Discussion

Let \( \overline{v}(t) = \|v_i\| \) be a vector of reference parameters, where \( v_i \) is a set of requirements to ATCS imposed by traffic control authorities; \( \overline{u}(t) = \|u_i\| \) is a vector of control inputs, where \( u_i \) is a set of control signals from the automated traffic control system (duration of enabling and prohibiting signals of traffic lights, information on electronic displays, green wave speed, etc.); \( \overline{y}(t) = \|y_i\| \) is a vector of output parameters, where \( y_i \) is a set of characteristics of the traffic flow after it has undergone the controlling signals. Then, a rigid control of traffic over a section of a road will be like shown in Figure 1.

![Figure 1. Diagram of a rigid road traffic control](image)

Here \( O \) is a transport flow (a single vehicle or a group of vehicles); \( P \) is a technical means of traffic control (TMTC). We assume, that dimensionality of \( v, u, y \) is the same. In this scheme, the functional of the automatic control system is that the technical means of traffic control shall \( P \) organize control in functions \( v, y \) in such a way, that the following property holds [1]

\[
\lim_{t \to \infty} |y(t) - v(t)| = 0,
\]

where \( t \) is the time of TMTC operation.

As evident from Figure 1 and (1), when selecting the rigid traffic control, the requirements to a transport flow implemented in given control inputs of the automatic traffic control system and its output characteristics are impossible to change during the operation of the system. At that, a possibility of reaction to probable perturbation (action of perturbing factors) is not available. Such a model of traffic control may find limited application on condition of absence of destabilizing factors on the road.

However, concentration of effort on increased efficiency of individual processes in road traffic, construction, maintenance and reconstruction, or performance of task by separate enterprises, as it is evident from practice of industrial manufacturing and distribution, has depleted possibilities for additional gains and is a dead end, as efficient action of one function of organization may reduce the total efficiency of others and that of the whole system as a result. Logistics unite various participants of material flow (i.e., subjects with different economic and other interests) in a common system.

A systemic approach implemented in logistics allows seeing the studied object as a complex of interlinked subsystems united by a common goal, revealing its integrative properties, internal and external connections. When using it in the road industry, the system that controls traffic, construction, maintenance and reconstruction of motor ways shall appear to authorities as a common system that includes moving vehicles, motorway, enterprises and organizations of the road industry, traffic control organizations, having the common goal: to attain full capacity of road traffic [5]. At that, all the road traffic is represented as a unified flow of vehicles, whose stop at individual sections means termination of its functioning.
Currently, in the considered case of the road traffic, there is growth in traffic volume, while the performance characteristics of motorways stay the same (or deteriorate). Reserves for increasing traffic capacity (widening of the carriageway, road surface improvement, increasing horizontal curve radius, seasonal road maintenance, construction of bottleneck bypasses, etc.) are largely depleted or require enormous time and resources to obtain an insignificant effect. With the help of logistics in road traffic provision, it becomes possible to compare the demand for traffic capacity (required traffic intensity) and supply of the traffic capacity provided by the road with the help of organizational measures with minimal additional costs.

*Logistical approach* to road traffic control is understood as implementation of a set of organizational and technical measures to increase traffic capacity and road safety by means of applying logistical principles and control methods.

It may be assumed, that application of logistical principles may shorten vehicle travel time (by shortening delays in moving on road), thus increasing the road capacity and vehicle safety.

However, the listed possibilities arise only on condition of continuous control over all flow processes in the motorway network. Information flow in the control processes of the traffic and other flows shall happen simultaneously with the traffic, and in some cases shall anticipate them. One of the causes initiating rapid development of logistics was progress in science and technology, first of all, computerization of process control, allowing control and coordination of flow process behavior. Use of computer technologies allowed for monitoring of all the stages in product movement: from primary source of raw materials through all intermediate manufacturing, storage and transportation processes up to final customer, which allowed vividly revealing enormous losses in existing material flow control systems.

One of the main tasks of logistics is creating an efficient integrated system for control and monitoring of material and information flows that provide high quality of product delivery. Thus, currently, there is a necessity for development of new, more efficient ways for organization and control of all the flow processes on the motorway network. Besides, emerging conceptually new possibilities of control: automated tracking of vehicle movement and cargo location on its way from manufacturer to customer with the help of satellite positioning systems and mobile communication; presence and movement of material reserves with RFID tags; immediate transfer of information particulars of transported cargo; real-time monitoring and control over all the stages of product movement; timely receipt, processing, analysis and change of information consignees; use of paperless technologies (electronic signature, electronic shipping documents); flexible adaptive traffic control at motorway sections, - will allow improving efficiency of traffic flow control to a completely new level, that will allow resolving issues of continuous control of all the flow processes in the road network. This requires creating information systems (at both local level of individual sections of motorways with limited capacity and the level of the road network as a whole) and information services that manage all the information flows and are responsible for activity of such system within a city or a region.

Logistical approach to the traffic control over the road network is attained by implementing the following logistical functions [1]:

- Adaptive traffic control over the motorway network using automated (automatic) complexes, services and systems [6, 7];
- Continuous study and correspondence accounting of vehicles [8];
- Continuous automatic monitoring of location and movement of vehicles with the help of space-based navigation positioning systems and cellular networks;
- Automatic generation of networks of technical means for traffic control [9, 10];
- Implementation of road maintenance and reconstruction measures aimed at a common goal: modern and exhaustive provision of motorway capacity[4];
- Timely informing road traffic participants about road repair and reconstruction, road accidents, traffic jams and congestions [4, 10].

Use of logistical methods for improving the processes taking place on motorways when transport flows operate will provide an opportunity to avoid traffic jams and congestions by reducing time lost by vehicles, thus improving their safety and safety of the road itself [11-13].
These requirements are taken into account in the automatic traffic control model with prediction capabilities shown in Figure 2.

\[
\begin{align*}
\Delta v_i + \Delta u_i + \Delta y_i & \rightarrow M(t) \\
\end{align*}
\]

**Figure 2.** A diagram of traffic control with prediction capabilities

Here \( \Delta M(t) = \|M_i\| \) is a matrix of hazardous factors; \( M_i \) is a set of influences that destabilizing factors and the environment exert on the traffic flow, \( \Delta \) is a correction of requirements and control inputs.

In this diagram, the functional goal of the logistic control system is that the technical means of traffic control \( P \), getting proactively corrected requirements to the traffic flow based on the forecast of road situation shall organize the traffic control in functions \( v, y \) in such a way that the following property holds [1]:

\[
\lim_{t \to \infty} \left( y(t) - v(t) - M(t) + \Delta \right) = 0,
\]

That is, correction of control inputs is implemented in the technical means of traffic control in advance, from results of operating the system in previous periods; correction value is equal to the sum of influence coming from destabilizing factors. However, anticipatory forecasting of the situation resulting from influence of multiple hazardous factors onto the traffic flow is a complex task, so this model of traffic control may find only limited application under conditions of influence from cyclic destabilizing factors.

An adaptive model of traffic control is devoid of such disadvantages [1]. Its diagram is shown in Figure 3. In this diagram, a property (2) holds, but correction of control inputs \( \Delta \) is performed from measured indicators of destabilizing factors obtained from vehicle movement transmitters. At that, due to application of the modern means of data analysis and transfer, delay between receipt of data on hazardous factors influence and correction of control inputs is insignificant.

\[
\begin{align*}
\Delta v_i + \Delta u_i + \Delta y_i & \rightarrow M(t) \\
\end{align*}
\]

**Figure 3.** A diagram of adaptive model of traffic control

This model allows for a flexible reaction to influence of destabilizing factors and may be employed for road traffic control, both in city streets, and on intercity motorways.

This information model of adaptive road traffic control may be implemented in the following scheme of logistical integration of road services and traffic safety control systems, shown in Figure 4.
Traffic control system
TCS ARTCC

Transport flow

Accident notification system
EMERCOM
Ambulance
Road Police
Rosavtodor

Vehicle congestion identification system
GIS Internet Services
CCTV

Figure 4. A diagram of logistical integration of road services and road traffic safety control systems

In this diagram, TCSs are traffic control stations of the national road police; ARTCC is an automatic road traffic control center; EMERCOM are divisions of the Ministry of Emergencies; GIS is a geographic information system; GSM are mobile communication providers; Rosavtodor are organizations of the Federal Road Agency.

Such a model of road traffic control allows combining all the vehicles into a whole and considering them as a transport flow. It allows applying logistical principles to the road traffic processes.

4. Conclusion
Application of logistical principles allows obtaining undeniable results from using logistics as a tool to increase efficiency of supply, production and distribution of production, quality of service, obtaining additional gains in functional fields of manufacturing, transfer, distribution and accumulation of material supplies. Using the logistical approach in organization and control of road traffic, as well as in the processes of road reconstruction and repair will allow reducing probability of traffic congestions and jams, shortening total travel time and increasing traffic safety.

Selection of the road traffic control model will influence the composition of the technical means used for road traffic control for sections of motorways, thus influencing road traffic control and traffic safety.

References
[1] Vostrikov A S 2006 Synthesis of control systems by localization method. (Novosibirsk: NSTU Press)
[2] Besekersky V A, Popov E P 1975 Theory of Automatic Control Systems. (Moscow: Nauka Publishing)
[3] Kozlov V N, Kupriyanov V E, Zaborovsky V S 1989 Synthesis methods for Automatic Control Systems. (Leningrad: LSU Press)
[4] Yermoshin N A, Yegoshin A M, Lazarev Y G, Zmeev A T 2017 Issues and methodological aspects in organization of road activities in the interests of military security of a state. a Monograph. (Saint Petersburg: VAMTO)
[5] Bolgarov N I, Fyodorov O V, Yermoshin N A 2014 A logistical approach to using various types of transportation. A monograph. (Moscow: KnoRus)
[6] VNIIBD MVD USSR 1981 Design and implementation manual for automatic control systems in road traffic on the basis of ASSUD. Ministry of Internal Affairs of the USSR. (Moscow: VNIIBD MVD USSR)
[7] Petrov V V 2007 *Automatic traffic control systems in cities. A Study Guide.* (Omsk: Siberian State Automobile and Highway Academy Press)

[8] Polukarov V M 1974 *Organizing Traffic Flows.* (Moscow: VNII of Road Safety)

[9] Pen'shin N V, Gavrikov V A 2013 *Technical means of traffic arrangement: Guidelines* (Tambov: TSTU Press)

[10] Khmara V V, Kabyshev A M and Lobotskiy Y G 2016 Automatic microprocessor-based performance diagnostics of switches of pneumatic transportation system. *IOP Conference Series: Earth and Environmental Science* 87

[11] Kremenets Y A 1995 *Technical Means of Traffic Management.* (Moscow: Transport)

[12] Martyushev N V, Petrenko Y N 2014 Effects of crystallization conditions on lead tin bronze properties. *Advanced Materials Research* 880 174-178

[13] Samoylenko V V, Lenivtseva O G, Polyakov I A, Laptev I S, Martyushev N V 2016 The influence of non-vacuum electron-beam facing on the structure of Ti-Ta layers formed on the surface of VT1-0 alloy. *IOP Conference Series: Materials Science and Engineering* 124(1) 012117