Digital object-oriented control models in automobile-road complex systems

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Abstract. The extensive development of the structures of the automobile-road complex requires optimization of the processes of their integration into the regional and global transport infrastructure. In order to effectively manage unstable traffic flows, automated control systems are developed that use complex algorithms based on the principles of artificial intelligence. The basis of this approach is the concept of transferring the concept of a control object from a generalized or aggregate traffic stream to a separate control element: a separate vehicle, a separate passenger, a separate consignment. The completed management process in the system of the road complex, which meets the current level of development of scientific and technological progress and productive forces, requires the use of digital object-oriented management models based on the creation of a unified communication and computer network for managing information flows as well as the development and application of control models physical objects of movement in the transport network, determining the optimal trajectory of movement of the latter. To form a control system based on object-oriented models, it is necessary to develop specialized analytical methods for multi-criteria evaluation of possible options. It is of fundamental importance that the developed methods can investigate the field of probabilities of changes in informational situations of the environment and are applicable to factors of any degree of uncertainty.

1. Introduction

The development of the structures of the road complex and their integration into the regional and global transport infrastructure cannot be based solely on the mechanisms of regulation of the “free” market. In this case, each interested explant of the transport system, and these are cargo carriers, owners of transport and storage complexes, municipal authorities etc. optimize “their own transport logistics and economy”, which leads to such a transport situation when the transport infrastructure does not satisfy everyone. An alternative to this approach is the use of mechanisms for synchronous or integrated optimization of the parameters of traffic flows and elements of the transport infrastructure: parking lots, interchange hubs, cargo terminals etc., which will reduce the total mileage of the rolling
stock, more efficiently use the power of both the road network and infrastructure of the transport and logistics system as a whole as well as to differentiate in time and space and optimally redistribute traffic flows of goods and passengers. Currently, the operation of control systems in the road complex is based on outdated ideas about the control object - the traffic flow. In this case, as a control object, a traffic flow has the following properties:

- non-stationary state (daily, weekly and seasonal unevenness),
- stochasticity (differences in the goals of the participants in the movement and their behavior),
- sustainability (periodic nature of travel),
- inertia,
- interconnectedness (presence of internal dependencies between flow parameters),
- insufficient manageability.

In order to effectively manage such an unstable object as a traffic stream, transport science today is developing more and more new approaches. Control systems have gone the way of development from local hard one-program regulation on separate sections of the transport network to automated control systems (ACS) using complex algorithms and principles of artificial intelligence. The next stage in the development of ACS are those operating on the principle of feedback with the flow or adaptive systems using various self-learning algorithms, systems that simulate the behavior of living organisms [1] and systems based on neural network technologies and artificial intelligence [2, 3].

When designing these systems, there is a tendency towards a transition to the so-called “Active Traffic Management” [4, 5]. This approach assumes a more intense impact on the behavior of traffic flows based on modeling and predicting changes in its parameters, which requires full integration of all local control systems. Coordination of control actions is considered an attribute of a complete management process. This level occurs when individual elements of the system begin to develop control actions on the basis of incoming information in the interests of the entire system as a whole. The stage of coordinating control actions requires maximum efforts to overcome organizational and technical barriers, since, as a rule, the creation of a unified communication computer network is required. At this stage, each participant must correlate their decisions with the overall management concept. That is, the concept of a control object is transferred from a generalized or cumulative traffic stream to a separate control element: a separate vehicle, a separate passenger, a separate consignment of cargo. Today, the integration of transport network components is carried out by transmitting information about the interaction between individual vehicles and transport network elements. In one study, more than 30 connections between the components of the transport network are highlighted [6]. Therefore, the completed process in any control system of the road complex that meets the current level of development of scientific and technological progress and productive forces requires the use of digital object-oriented control models:

- creation of a unified communication and computer network for managing information flows;
- development and application of object-oriented models for managing physical objects of movement in the transport network, forming optimal trajectories of movement of the latter.

2. Problem Statement

When considering issues of interaction of objects related to each other by a number of diverse relationships, it is necessary to develop algorithms that are able to maintain integrity relations between objects [7]. Modern high requirements for the reliability and security of information systems lead to the fact that all the main decisions in the field of organizing information exchange processes have a client-server architecture. This approach allows us to restrict access to confidential information by concentrating all the functions of direct data management in a single center. As a rule, various database management systems (DBMS) are used as server software. A significant number of DBMSs are based on the relational principle [8], when tables or stored procedures are the means of interaction. The main disadvantage of the relational interaction model is that the designed system as a set of tables is very often difficult for analyzing and understanding of processes. In turn, with the increasing complexity of the system, this leads to the inability to fully monitor all the necessary places and
procedures for implementing changes, and the process of developing the system itself becomes poorly managed or uncontrollable. An alternative to this approach (relational data model) is an object-oriented approach. When using an object-oriented approach, a program should not only describe objects and their properties in the form of criteria and the relationships between them in the form of goal setting, but also describe their interaction (methods) in the form of operations on objects.

3. Materials and Methods
A clear advantage of the object-oriented approach is the conceptual proximity in any subject area to an arbitrary structure and purpose of the system. At the same time, attribute conversion mechanisms or methods should allow building derivative objects and structures on the basis of basic ones, thereby creating a model in a more complex subject area with the necessary properties, providing the possibility of constantly analyzing and making changes if necessary. In this case, objects and methods are polymorphic, which makes the software more versatile and flexible [9]. Despite the clear advantages of the object-oriented approach, object-oriented control systems are still not widely used [10]. At the same time, hybrid object-relational DBMSs are widely used, which partially use object-oriented principles of working with data, but at the same time, data storage is performed during the implementation of the relational model (Table 1).

| Solution option                  | Solution description                                                                                                                                 |
|----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| Direct work with the control system | As an automated workstation (AWS) a specialized application is used that directly accesses the control system (CS). This scheme is used for small application systems; the implementation of this approach for complex databases makes it difficult to develop the system |
| Using an intermediate layer      | As an AWS specialized browsers are used that do not access the CS directly, but some kind of intermediate layer, which then accesses the CS directly. The use of the intermediate layer as a link between the AWS and the CS enables the AWS not to depend explicitly on the CS and increases the possibility of developing systems |
| Using a server application       | The AWS directly refers to a specialized application (server), which then accesses the CS directly or using an intermediate layer. This 3-level architecture makes it possible to implement logic on the server, thus increasing the security of working with data, increasing scalability |

The given review of options for possible architectural solutions in the development of an information system that provides simultaneous access to information of many users allows you to create a scheme for using technologies with an intermediate layer on the server. When applying the object-oriented approach to implement the interaction between objects (classes), an event model is implemented. The scheme of this model is shown in Figure 1.

The main result in the interaction using the event model is defined in the following. The event handler object (B), the data and state of which depend on the state of the object (A), implements a subscription to the event of a state change or change of the object (event source). When an event occurs (when the state or data changes), object (A) generates an event that causes the execution of the corresponding handler object (B). The use of the event model for the implementation of object relationships in order to maintain the integrity of relationships in the control system allows us to perform the relationship between implicit objects, thereby simplifying the procedures for adding new and changing existing relationships. This mechanism is good enough if the objects are fixed once and fixed all the time the application exists or until they are in demand. But when forming control systems intended for simultaneous work with a sufficiently large number of interconnected objects, when
objects are stored in the CS and loaded for work only when performing direct actions with them, it is unacceptable. In this case, additional tools are needed in the form of interaction control subsystems that implement event-based models of interaction of objects in the intermediate layer.

Naturally, when developing a control system that implements an event-based model of interaction between objects within an intermediate layer on a server, support for events of two types is required:
- events that occur when performing actions with any object of the system – object events.
- events that appear when any particular point in time occurs – temporary events.

Event handlers also need to be divided into two types:
- synchronous handlers, when the processing of an event occurs immediately at the moment of its occurrence, that is, the same transaction in which the event occurred (happened);
- asynchronous handlers, when the event handler is queued and implemented during system downtime, for example, in a separate transaction.

The use of asynchronous handlers will reduce the time it takes to complete a transaction and, accordingly, will reduce the response time of the CS to user requests. It is also possible to increase the overall performance of the CS by implementing additional processes, including on individual computers, when invoking asynchronous processors.

The main elements of the object interaction control system under consideration are the queue of asynchronous event handlers for events and the storage of event subscriptions. When implementing a new subscription to an event, information about it is added to the subscription repository. Each record may contain certain information about the source object:
- event of the source object;
- type of subscription – synchronous or asynchronous;
- handler object;
- method of the handler object that must be called for to process the event.

When any event occurs, all subscriptions to the source object event are searched for in the repository, then, depending on the type of subscription, either a direct access to the handler object is

Figure 1. Event interaction scheme
made, or an entry is added to the queue of asynchronous handlers. If the asynchronous handler is accessed during system downtime, this increases its performance. It is important to note two main circumstances necessary when implementing the subsystem for managing interactions between objects:

1. Technological. Any object that is an event handler or source must have a unique identifier, using which one can load the desired object from the database into the application memory. The identifier should allow storing links to objects in the subscription description, which are event handlers and sources.

2. Scientific and methodological. The method of the processor object to be implemented must be formed, formalized and programmed as an analytical decision-making model based on information about the state or current state of the source object, for example, in the form of tables of values of the efficiency of actions in a multi-criteria goal setting structure.

4. Discussion of Results

Any level of tasks of information systems, the solution of which is aimed at increasing the efficiency of their functioning by increasing the completeness and efficiency of information about the control objects and the systems themselves, and also at improving the quality of generated control actions, requires optimization of control decisions for participants in the movement based on object-oriented modeling (OOM). The object-oriented approach involves the formation of an abstract representation of the structure of any system in the form of a hierarchy, which is necessary to study the functional interactions of its objects and their effects on the entire system as a whole [11]. The stages of the process of building a system hierarchy are as follows:

- The boundaries of the system are determined based on the initial information state (degree of certainty) for the given environmental conditions of the system functioning in the form of a formalized model of the source database based on possible solutions depending on the criteria being designed.
- The goals of the system are fixed as an assessment of the highest level of the hierarchy based on the significance of the interaction of various levels, and not directly dependent on the objects of the system at these levels.
- Criteria are identified as measuring instruments of the control process that affect the solution of system tasks. Obviously, each criterion should reflect the main function at its level in decision-making in the system, and not a secondary one.
- A hierarchy of criteria is defined. The simplest hierarchy is linear, ascending from one level of elements to a neighboring level. In a nonlinear hierarchy, the upper level can be both in a dominant position with respect to the lower level, and in a dominated one (for example, in the case of information flow). In the mathematical theory of hierarchies, a method is used to assess the impact of a level on a neighboring upper level by composing the corresponding contribution (priorities) of the lower level elements with respect to the upper level element. This composition can spread up the hierarchy.
- A set of technical indicators or formalized values is developed for each criterion, ensuring the requirements for the functioning of the system.
- A method for solving the problem is described, which consists in determining the permissible values of the parameters that define not only the performance of the system and its objects, but also the effectiveness of functioning in general, taking into account the goal-setting.

In the developed hierarchical structure of the system, the question of the optimal number of objects that are subordinate to the senior object and (or) located at the same level is always relevant. The number of such determines the degree of controllability in the system: the more of them exist, the less is the controllability in the system. On the other hand, a large number of seniority levels in subordination are justifiably undesirable, as it leads to an increase in the timeframe for promoting information in the system. In this case, the solution to the controllability problem in the system is determined by the effectiveness of the mathematical apparatus aimed at finding the optimal solution [12]. If we consider the management process as a series of specific organizational and administrative
measures and technical measures for the development of existing systems of the automobile-road complex, then in order to ensure their joint work, at least three main groups of criteria must be taken into account:

- completeness and effectiveness of implementation of the main functional tasks of a control system;
- volumes and complexity of work;
- possibility of development in the process of further functioning.

The initial decomposition of the hierarchy of the CS structure based on OOM for the development of solutions is shown in Figure 2.

![Diagram showing the initial decomposition of the hierarchy of the CS structure based on OOM](image)

Optimal system condition: \( D(\kappa_n) \rightarrow \text{opt} \)

5. Conclusion
In the structure of the OOM-based control system presented in Figure 3, it is necessary to apply analytical methods for multi-criteria evaluation of possible options for operations, which allow operating with initial data and obtaining the optimal solution analytically. In real conditions, the
effectiveness of an ACS functioning can be determined by a large number of criteria, in addition to those considered. Therefore, it is important that the developed methods investigate the field of probabilities of changes in informational situations of the environment and are applicable to factors of any degree of uncertainty [13], that is, rely on the Bayesian rule. In other words, if previously known information about a process exists, then it is possible to determine the probability of a new event in a given process more reliably.

\[
P(A|B) = \frac{P(B|A)P(A)}{P(B)}
\]  

(1)

where \( P(A) \) is the probability (a priori) of an event \( A \); \( P(A|B) \) is the probability of event \( A \) in case of event \( B \) or a posterior probability; \( P(B|A) \) is the probability of event \( B \) in case of reality (occurrence) of event \( A \); \( P(B) \) – is the probability (full) of event \( B \).

Application of the Bayesian rule will make it possible to remove objective difficulties in choosing a system for calculated cases that arise in the process of solving the multicriteria problem of evaluating actions in ACS under the condition of uncertainty [14]. Namely, a number of formal-logical methods is based on the Bayesian rule that allow one to analytically determine the probabilities of possible events when there is information about previous events or the state of the system as a whole [15].

References

[1] US Public Law 102-240 Intermodal Surface Transportation Efficiency Act of 1991
[2] US Public Law 105-178 Transportation Equity Act for the 21st Century (TEA-21) 1998
[3] History of Intelligent Transportation Systems U.S. department of transportation, report FHWA-JPO-16-329, 2016
[4] Synthesis of Active Traffic Management Experiences in Europe and the United States 2010 FHWA
[5] Active Traffic Management for Arterials 2013 National Cooperative Highway Research Program
[6] Building the ITI: Putting the National Architecture into Action, Mitretek Systems, FHWA, April 1996
[7] Romanov B L and Slobodetsky D Ya 2009 Interaction of objects in an object-oriented environment Proc. of the Instit. for Syst. Anal. of the Russ. Acad. of Sci. 45 59–67
[8] Zaliznyak E 2005 “Three Fat Men” DBMS occupied the market for life CNews 15th August Retrieved from: http://www.cnews.ru/reviews/index.shtml?2005/08/15/184770
[9] Meliep B 2005 Object-oriented design of software systems (Moscow: Russ. edition)
[10] GOST R ISO 14813-1-2011 Intelligent transportation systems. The scheme of building the architecture of intelligent transport systems Part 1 Service Domains for Intelligent Transport Systems, Service Groups and Services (Moscow: Standartinform)
[11] Kuzin M V 2009 Simulation model of coordinated traffic flows in the city road network Inform. Technol. of model. and control 4(56) 502–8
[12] Mesarevich M 1973 Theory of hierarchical multi-level systems (Moscow: Mir)
[13] Kornikov V V, Seregin I A and Khovanov N V Bayesian model for processing non-numeric, inaccurate and incomplete information on weight coefficients Retrieved from: http://inftech.webservis.ru/it/conference/scm/2000/session3/kornikov.htm/
[14] Pegat A 2009 Fuzzy Modeling and Control (Moscow: BINOM, Lab. of knowledge)
[15] Karelina M Yu, Arifullin I V and Terentyev A V 2018 Analytical determination of weight coefficients in a multi-criteria evaluation of effectiveness of vehicles Bull. of the Moscow Automobile and Road State Techn. Univer. (MADI) 1(52) 3–9