The intelligent control concept of the transportation process on the Belarusian Railway

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***Abstract*—directions for the development of transportation control systems have been established. The basic provisions of the concept of creating an intelligent system for managing the transportation process on the Belarusian Railway are described. The generalized objective function of the effectiveness of intelligent control is formulated. An end-to-end control loop is described. The main functions of the intelligent control system and stages of system implementation are determined.**

***Keywords*—transportation process, transportation organization, operational task, end-to-end management cycle, transportation resources, intelligent management**

Improving the efficiency of the functioning of the transport system is embedded in many strategic documents of the Republic of Belarus. For example, [1] provides for «Acceleration of scientific and technological progress and the scale of the digitalization of the economy». «. . . In the context of the exhaustion of factors of extensive production growth, the main accelerator of economic development is its digitalization. Digital platforms and artificial intelligence technologies gradually go beyond the industry, covering all spheres of life».

In accordance with [1], at the first stage, as a priority area of innovative development of transport, an increasing of the transport processes informatization level through the intelligent control introduction and monitoring systems is defined. The second stage 2026-2035 provides the accelerated development of the intellectual transport system, which will allow to reach the world level of development of the transport complex of the Republic of Belarus and increase its competitiveness.

The intelligent transport systems implementation is defined in more detail in [2], which provides the «creation of an intelligent transport system of the state integrated with the transport systems of the EU and the EAEU».

To implement the principles of intelligent management in railway transport, scientists at the Belarusian State University of Transport have developed a concept for introducing an Intelligent Transportation Control System (ITCS).

The goal of creating the ITCS is to form a unified transportation management business process that will increase the efficiency of railway transportation activity and the level of transportation safety. These goals are achieved by the using of information and communication and intelligent technologies in the operational management system.

Using ITCS allows you to use the accumulated array of experience in the formation of effective management decisions (MD), manage production processes in real time, plan work, simulate and predict the development of operational situations at the entire control range.

Intelligent transportation management aims to:

- implementation of integrated operational management and the use of a single information model by all participants in this activity. The information model includes a database, knowledge base, experience base and describes end-to-end production processes of all departments and all levels of management;
- formation of operational information services and technological interaction of participants in the transportation process. Technological services include daily and ongoing planning, implementation of agreed and approved plans;
- implementation of end-to-end automated control of the execution modes of technological processes for managing operational work;
- operational and process economic evaluation of the developed plans and technological processes of operational work;
- operational forecasting and cost estimation of unproductive losses of technological processes.

For all levels of management (network, road, linear) and operational tasks, unified principles are used to describe the problem environment and search for rational MD. These principles include:

1) The use of adaptive planning methods and scenario approaches, which in real time, taking into account the current situation, should ensure the development and adjustment of plans (both voluminous and detailed) for all business processes implemented at the training ground.
   Adaptive planning methods should be used for operational management, while scenario methods are used for annual and monthly planning. Technical norms (volume plans) formed using scenario methods should be the source data and target indicators for adaptive planning (detailed plans). The results of annual and monthly planning are stored in IAS PUR GP and can be used as target documents for other systems.
2) Automation of end-to-end business processes formed on the basis of a comprehensive digital model of the transportation process, which should be the basis for the design, implementation and operation of the ITCS. Using a digital model will allow us to close existing information gaps in management processes.
   To build a comprehensive digital model within the ITCS creation process specific measures must be provided to ensure the development and implementation of end-to-end management processes that take into account the specifics of the activities of various subdivisions of the warhead with the simultaneous alignment, regulation and proper information support of the processes of interaction

of the transportation process participants. An integrated digital model of the transportation process should be formed in the IAS PUR GP and used by all the functional subsystems of the ITCS in the development and implementation of MD.

3) The use of a single platform for the development of ITCS subsystems to achieve maximum synchronization and information security of automated business processes. At the same time, a single platform should provide:
   - Creation of a unified information environment for automation of MD development processes for the planning, implementation and control of end-to-end production processes, taking into account reliability, safety and risk assessment indicators;
   - integration and ensuring the interaction of ITCS and automated systems operating on warheads in a single information space;
   - the using of complete, consistent regulatory and operational reliable information in the ITCS.

   The implementation of a single platform should include an ontological description of the subject area, the construction of a conceptual model and a digital model of the transportation process, distributed architecture, intelligent planning methods and a number of other functions [3].

   The unified platform and functional subsystems of the ITCS form the planned and regulatory MDs for subsequent automatic implementation or for consideration by dispatch personnel.

   The technological subsystems of the ITCS ensure the implementation of SD at specific control facilities.
4) Technical and economic assessment. All the results of the functional subsystems of the ITCS should be accompanied by an economic assessment and analysis of the achieved technological effects in the implementation of the developed plans. In ITCS, a comprehensive assessment of MD should be implemented, including modules for the intellectual formation of assessment criteria and weighting criteria for their significance for various production situations [4].
5) The ITCS software should have an effective system of settings for further replication. Implementation at a new landfill should be carried out by adjusting the system using the appropriate settings and adding reference information, and not by developing subsystems again for each landfill.

The use of unified approaches to the description of the problem environment will provide the following advantages compared to “traditional” methods of solution:

- reduction of uncertainty in the source data through the use of harmonized source data;
- reduction of entropy in solving operational problems by using the results of solving some problems as source data for solving others;
- the ability to search for global extrema in assessing the effectiveness of the transportation process, and not local for each individual task;
- providing an objective assessment of the magnitude of the impact of the results of solving one operational problem on the development of control solutions to another problem.

The main priorities for the creation of the ITCS are:

- improving the quality of adopted MD and solving new operational problems on the basis of flexibly formed optimality criteria;
- optimization of the total costs of all participants in the transportation process by improving the quality of planning and monitoring the implementation of operational plans;
- improving the safety of the transportation process as an essential condition for the effective functioning of the ITCS;
- creation of ITCS as a modular adaptive system, which subsequently should be effectively integrated into the digital information space of the warhead, the transport system of the Republic of Belarus, transit transport corridors, and the EAEU.

The function of the functioning efficiency of the ITCS can be described in general terms by the expression

$$F_i(\overline{a_i}, \overline{b_i}, \overline{c_i}) = F_{1i}(\overline{a_{1i}}, \overline{b_{1i}}, \overline{c_{1i}}), \dots, F_{Wi}(\overline{a_{Wi}}, \overline{b_{Wi}}, \overline{c_{Wi}}), \dots, F_{Yi}(\overline{a_{Yi}}, \overline{b_{Yi}}, \overline{c_{Yi}}) \rightarrow max_{a_i \in \Omega},$$

where F_i – vector of optimality criteria characterizing the quality of adoption of MD at the i-th stage of decision-making; $i = 1, \dots, j$ – number of decision stages; $(a_i) = (\overline{a_{1i}}, \overline{a_{ti}}, \overline{a_{\psi i}})$ – vector of technical parameters at the i-th stage of decision making; $(b_i) = (\overline{b_{1i}}, b_{ti}, b_{\psi i})$ – vector of technological parameters at the i-th stage of decision making; $(c_i) = (\overline{c_{1i}}, \overline{c_{ti}}, \overline{c_{\psi i}})$ – vector of unmanaged parameters at the i-th stage of decision making; $\psi = 1, \dots, t$ – the number of subsystems of the ITCS that are involved in the development and implementation of MD; $y_i = 1, \dots, w_i$ – number of optimality criteria at the i-th stage of MD development.

Criteria for the transportation process optimality include, for example, the car’s turnover, route speed, the need for transportation resources, the capacity of infrastructure elements, fulfillment of contractual obligations, labor productivity, the need for locomotives and locomotive crews, and the cost of fuel and energy resources. The list of criteria, depending on the operational task to be solved, can vary over a wide range, while the number of optimality criteria and their structure do not affect the efficiency of adoption of MD.

The set of options $\overline{a_i}, b_i, \overline{c_i}$ can be represented as a combination of technical, technological parametric groups and uncontrolled environmental parameters.

The group of technical parameters include: for train work: the number of tracks on stages and intermediate stations, the number of train locomotives with details on series and types of work, the number of locomotive teams, etc. for station work: the number of technical and commercial maintenance teams in the subsystems of stations, the number of tracks in the parks of technical stations, the capacity of cargo fronts, etc.

The group of technological parameters include:

- for train work: train mass norms, train length norms; the presence of technological "windows" and their duration; type of train schedule. train formation plan, local cargo distribution schemes, etc.;
- for station work: sorting slide technology (with one, two or three locomotives); specialization of tracks in the sorting fleet, specialization of shunting locomotives, number of rides at local work stations, permissible deviations in length and mass of formed trains, etc.

To uncontrollable parameters: the technical condition of the car, weather conditions, etc.

Depending on the formulation of the control problem, individual groups of parameters can be considered both technological and uncontrollable. For example, the dimensions of the movement when developing a train schedule are technological, and when developing a station work plan, they are unmanageable. In the future, we will assume that the parameter refers to technical or technological (controllable), if for at least one ITCS subsystem it is. A parameter refers to uncontrollable parameters if no subsystem of the ITCS can form a control unit providing a change in the parameter.

Managed and unmanaged parameters can be described quantitatively (train mass rate), in the form of logical relationships (local cargo distribution scheme) or have a fuzzy description (flea runner, difficult weather conditions, etc.). In ITCS there must be mechanisms for describing and then comparing the parameters of various forms of presentation.

In ITCS a lot of controlled parameters $\overline{a_i}, \overline{b_i}$ are both initial data for the formation of rational MD, and the results of the functioning of the ITCS.

The set of uncontrollable parameters are subject to identification as describing environmental conditions, i.e.

$$F_i(\overline{a_i}, \overline{b_i}, \overrightarrow{c_i}) = F_{i+1}(\overline{a_{i+1}}, \overline{b_{i+1}}).$$

That is, at what environmental parameters the MD was obtained and how effective it was. The set $\overline{c_i}$ one of the components of the system knowledge base.

Thus, when modeling technological processes in the ITCS, among the admissible set Ω, it is necessary to find such control parameters and form such MD that will ensure the maximization of the target function F.

An end-to-end cycle of the transportation process management should be implemented at ITCS, including all levels (road, department, linear) and periods (long-term, medium-term, operational, current) of planning. The end-to-end cycle of the transportation process control includes modules (figure 1):

- infrastructure management;
- on-line digital model of the events of the transportation process;
- on-line modeling of processes;
- a module for the formation of control decisions (planners and problem solvers);
- module for assessing financial results and the formation of an array of experience;
- strategic planning.

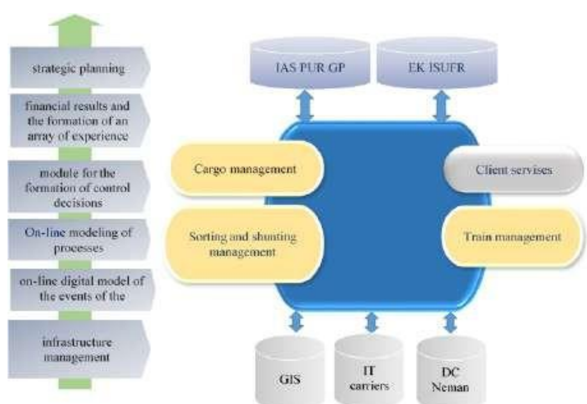

Figure 1. Diagram of the functional interaction of ITCS with external systems.

The functions of the ITCS are implemented through technological and functional subsystems.

Technological subsystems of control objects

A.1 Railway stations;

A.2 Dispatch sites (circles).

Functional Subsystems

B. Annual and monthly planning:
- B.1 Applications from customers for the transport of goods and the development of a plan for the transport of goods;
- B.2 Applications from carriers for the use of infrastructure services;
- B.3 Approval of applications;
- B.4 Development of a plan for the formation of trains;
- B.5 Development of a regulatory train schedule;
- B.6 Development and selection of a variant plan for the formation of trains;
- B.7 Development and selection of a variant train schedule;
- B.8 Technical regulation of operational work;
- B.9 Calculation of the required operating fleet of wagons and locomotives.

C. Operational planning:
- C.1 Operational planning of train and freight work:
- C.2 Ongoing planning of train and freight work;
- C.3 Determination of the current need for an operated fleet of wagons and locomotives;
- C.4 Linking rolling stock to applications;
- C.5 Linking compounding with a predicted train schedule. Garter locomotives and locomotive crews to trains.

D. Operational management and regulation:
- D.1 Dispatching and traffic regulation;
- D.2 Development of a forecast train schedule, the implementation of the "Auto dispatcher" function;
- D.3 Implementation of the function "Auto";
- D.4 Operations associated with the movement of loaded and empty wagons;
- D.5 Shunting work at stations;
- D.6 Loading, unloading and other initial and final operations;
- D.7 Technical inspection and maintenance operations;
- D.8 Commercial service operations;
- D.9 Registration of electronic shipping documents;
- D.10 Other operations with objects of transportation.

E. Control, accounting and analysis:
- E.1 Formation of accounting and reporting data;
- E.2 Analysis of the performed transportation.

The creation of the ITCS is a time-distributed process in which functional subsystems are developed in series and parallel. When designing subsystems, the possibility of their autonomous functioning is provided. In this regard, it is necessary to determine such conceptual approaches to the creation of the ITCS elements, which will allow to obtain a synergistic effect during aggregation and achieve the goals of creating the system.

The creation of the ITCS involves three main stages:

1) Creation of information and mathematical models of the transportation process on the basis of a unified road data transmission network, development and implementation of information and analytical systems. Integration of microprocessor systems, diagnostic and monitoring devices for infrastructure and rolling stock with information management systems. The introduction of GIS technology. Completion of work on the creation of automated planning systems for train and freight work. The goal of the first stage is to create a digital model of the railway.
2) Development and implementation of intelligent planning information systems focused on the operational

control center of the freight control center and line level facilities. Development of forecasting modules for the transportation process of the situation for 3, 4, 6, 12 hours, taking into account external factors for the transportation process. Development of technical and economic assessment modules for management decisions (plans) and their integration into existing MD. Target: implementation of management decision support systems and technical and economic assessment modules in existing MD.

3) Transition to intelligent forecasting, planning, management and decision support systems (automation of management, decision making automation to prevent difficulties in train work, optimization of regulatory measures), development of promising measures, development of the necessary technical, technological and regulatory documentation. The formation of an array of experience and training subsystems ITCS.

Target: the introduction of intelligent systems for the automatic control of the transportation process.

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Система интеллектуального управления перевозочным процессом на Белорусской железной дороге

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Установлены направления развития систем управления перевозочным процессом. Описаны основные положения концепции создания интеллектуальной системы управления перевозочным процессом на Белорусской железной дороге. Сформулирована обобщенная целевая функция эффективности интеллектуального управления. Описан сквозной цикл управления. Определены основные функции системы интеллектуального управления. Определены этапы внедрения системы.

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