Intelligent Management of the Railway Transportation Process: Object Model

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***Abstract*—In the article an overview of existing intelligent approaches to the management of the railway transportation process is given and key takeaways of developed object model are described.**

***Keywords*—Intelligent management, railway transportation process, making up plan, car traffic processing**

I. Introduction

Railway transport is the united production and technological complex includes railway infrastructure, rolling stock and other assets to ensure individuals', legal entities' and governments' needs in transportation under the conditions of a public contract, and in performing other work (service) which are depended on such transportation. The goal of present-day railway transport is to shape competitive transport product which will meet customer requirements. Now it is more complicated to perform.

II. Overview

Even in the classical task of managing the transportation process and the satisfaction of all customers it is difficult formalized and has a large dimension. For example, the length of the Belarusian Railways is 5.5 thousand kilometers. Every day in the transportation process involved more than 25,000 wagons, 500 locomotives, which are organized into trains and transported millions of tons of cargo. At the same time the work of all departments of trains making-up and traffic handling should be connected in the unified technology.Development of the transport sector and improve the quality of the transport product implies the need to create a different kind of technical systems, which should have a high degree of autonomy, adaptability, reliability and quality of functioning in conditions of uncertainty.However, the major sources of uncertainty in the manifestation of management tasks are the following factors

- the complexity of the formal description of the control objects and tasks with taking into account the measurement errors of the necessary data and calculations;
- vagueness of the operation purpose and control problems;
- not stationarity of the object parameters and control system;
- priory uncertainty of situation and working conditions;
- the presence of random effects of the environment;
- distortion of the incoming input data in the remote transmission channels.

It becomes difficult to solve the problem of traffic management in such conditions by conventional methods, even using automated control systems, and in some cases impossible. The adoption of unsustainable management decisions leads to violations of the goods delivery timeliness, to inefficient rolling stock usage, to increasing of the transport operation cost.

To increase the efficiency of management of transportation process in railway transport is possible due to the introduction of intelligent technologies. Consider the international experience of using such systems in transport. Currently, considerable attention is given abroad in the creation of ITS (intelligent transport system) in railway transport . China, India and others have joined to the recognized world leaders (Germany, UK, USA, Japan).

For example the Traintic company provides technology solutions for the railway sector, focused on the intellectualization of communication and information systems. Primarily, these are modular system of train control center, manage and monitor of the rolling stock state, based on the communication standards TCN. They allow real-time control of locomotive unit temperature, train speed, fuel level, etc. The solutions of Traintic company implemented in Madrid and Brussels metro, commuter trains in Mexico and Northern Ireland, in the organization of high-speed movement in Turkey [1].

In EU countries developed ERTMS system, which provides information exchange between objects of infrastructure, rolling stock of different carriers and customers. The system also has the ITS elements: SIGNAL subsystem, providing passengers with information before and during the journey, reservation and payment systems, luggage management and management of connections between trains and with other types of transport; cargo transport requests subsystem, included information systems (real-time control of shipping and movement in the trains), distribution systems, reservation, transportation payments and billing, organization of information interaction with other types of transport and forming of electronic accompanying documents.

Construction of the system is based on the functional and technical standards of the TSI, that is aimed to the organization of the consistent data exchange between the railway infrastructure managers, carriers and other participants in the transportation process.

China Railways has achieved specific results in the creation of ITS [2]. They are developing Railway Intelligent Transportation System (RITS) that should be built as a new generation of railway transport system aimed at the integration of technology in various fields: electronics, communications, data processing, control and diagnostics, automation and mechanization, support management decision-making. The goal of this development is to improve the safety and efficiency of the transportation process, improve the quality of customer service at a lower price. As part of the system creation RITS architecture was designed and guidelines for intellectual infrastructure of national rail transport system have been identified.

Indian Railways put similar goals and objectives when creating the RITS (increase efficiency, improve safety and better quality of service) [3]. In the development is used smart navigation system technologies, emergency situations and security monitoring intellectual system, intelligent railway management system, intelligent train control center and monitoring system, modern communications technology.

Active work on creating RITS conducted in the UK. For this purpose, it establishes an independent ITS Association, which includes 160 corporate members. There are already a number of its applications that can help rail operators and passengers. Developed ITS technologies are combined in a categories: cost, carbon, capacity, customers.

Implementation of intelligent control technology in railway transport provided by Russian Railways JSC Development Strategy until 2030 [4]. For this purpose a project to create a Unified Intelligent rail control system is started. The need to create such a system on the railway due to the complexity of tasks and environmental dynamic environment that requires continuous adaptation of the system to external influences. Currently defined the overall architecture of the system, some theoretical problems are solved, accumulated experience in creating application solutions.

The importance attached to the ITS improve the efficiency of basic production processes with strict implementation of safety requirements. Creating ITS Russian Railways envisages the creation of an appropriate intellectual infrastructure, which includes:

- the creation of a common information space, which must necessarily include a high-precision coordinate system and a digital base, built using GLONASS / GPS technologies;
- digital radio system with all the facilities of the rolling stock and railway transport infrastructure;
- control system of the rolling stock location on the infrastructure facilities;
- system diagnostics and predictive condition monitoring wagons and locomotives;
- system of situational monitoring and prediction of critical situations on the basis of situational centers;
- intelligent operational work management system.

An analysis of existing management systems following conclusions can be made on the railways:

- ITS no unified structure, and are not formalized requirements and rules of its creation;
- for the majority of current ITS term "intellectual" is used incorrectly as soon as they can be attributed to information or computerized control systems, with the main signs of intelligence for them are missing;
- from the rest of the ITS Group, virtually all systems are " intellectual" a little, that is, for their inherent intelligence trait 1-2.

Thus, the task of creating intelligent rail transport systems remains unsolved. When creating intelligent systems of rail transport requires not only high-quality mathematical formulation, but also knowledge of the approaches to the maintenance of transport problems.

III. Object model

Since rail transport is a complex system that includes connected with each other elements, conflicted over resources agents, assumes achieve different, including conflicting, targets, to describe it is necessary to form the semiotic models. In general, the semiotic models can be specified by the fourth:

$M = \langle T, R, A, S \rangle$

where
T - a plurality of base elements;
R - syntax rules;
A - the system of axioms;
S - semantic rules.

Let's define a set of basic elements of the semiotic model T "Railway transport" and determine the object model. In rail transport, as the system can distinguish the organizational, functional and elemental content.

Organizational railway control system is built hierarchically (Figure 1).

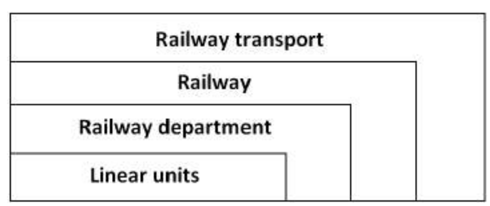

Figure 1. Organizational railway control system diagram

For example, the Belarusian Railway includes 6 departments (unitary enterprises). Departments include 362 large and small stations, 17 locomotive depots, 12 depots, 20 distances the way, 13 signaling and communication, 7 distances electricity and other enterprises. Each of the linear unit may include departments and workshops.

The functional content assumes the system decomposition by functional features. On a railway transportation the next relevant services are responsible for the basic functions implementation: transportation, passenger, locomotive, power supply, etc. Each service has its own organizational structure and implements control over the departments of departmental and on linear levels and the corresponding linear units.

Through the management process multiple services can both complement each other (when forming the trains responsible for the train set making up is a service of transport, for the technical condition of railroad cars - cars, for the provision of locomotives - locomotive) and conflict over resources (when organization train handling on the district there is a conflict in the priority handling of freight and passenger trains).

The elemental structure of the system is dependent on functional and defined list of solving operational problems. Let's take a look to the elemental structure of "transportation process management" subsystem.

The main model object is the station. According to its functional purpose and amount of work stations are divided into marshalling, district, freight, passenger and intermediates. Stations participating in the trains making up, belong to the technical category. Technical stations interconnected by rail districts.

According to the graph theory, the railway is the transport network, which can be described by a symmetric graph $G\left(\{i\},\{i,j\}\right)$, composed by node set S_i (stations) and oriented arc set (rail districts) $\{D\left(i,j\right)\}\, i,j=\overline{1,p}$ where p – the total number of stations. Arc $D(i,j)$ leads from node *i* to the node *j* and have weight t_{ij}^{G}. Weight of arc t_{ij}^{G} according to the optimization criterion can be **train travel time** between neighboring stations on the G polygon, **length** between stations *i* and *j*, **transportation cost** of car traffic unit by this arc [5].

Graph to describe of the Belarusian Railways polygon is shown in Figure 2.

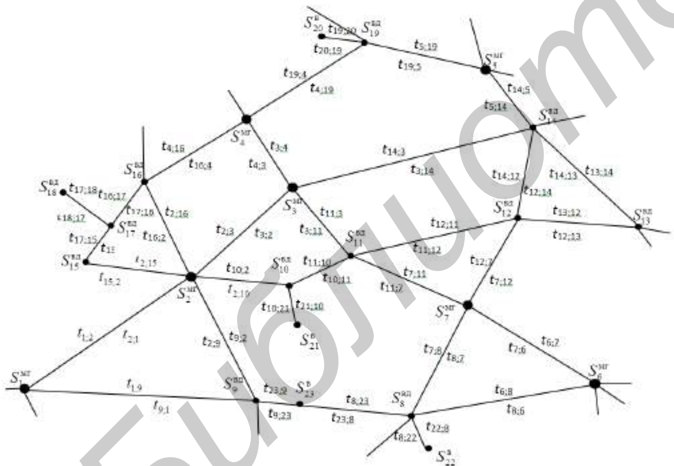

Figure 2. Graph to describe of the Belarusian Railways polygon

Transportation process can be divided into two parts: train operations and shunting operations. Train operations are performed on the rail districts and spans (graph arcs). Shunting operations are performed on stations (graph nodes).

Graph arc description example with span details are shown on Figure 3.

According to Figure 3 railway is composed by set of districts. Each district belongs to appropriate Railway department (NOD). NOD-2 includes districts Grodno-Kuznitsa,

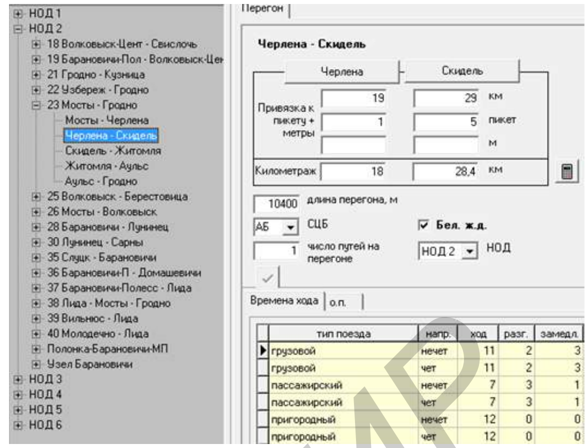

Figure 3. Definition of "span" object

Mosty-Grodno and others. District Mosty-Grodno includes spans Mosty-Cherlena, Cherlena-Skidel, Skidel-Zhidomlia and others. Train handling technology and parameters for solving the operational tasks are depend on span properties.

Each node S_i of railway network G is characterized by property set, that defines station functionality and possibilities on the train making up and handling.

Operational possibility *i*-station is defined by technically permissible processing cars limit n_{Ti} and can be described as a composed function

$$n_{TS}^{nal}=f_1\left(M_g;M_{vf};k_n;N_{tr};N_{trpr};N_{tny};N_g;\{t_{tex}^{z}\}\right)$$

where

M_g - locomotive number, that works on the yard;

M_{vf} - locomotive number, that works on the draw-out track;

k_n - train address number, that is made up on station;

N_{tr} - through train number, trains without processing;

N_{trpr} - through train number, trains with partial processing;

N_{tny} - track number in sorting yard;

N_g - estimated capacity;

$\{t_{tex}^{z}\}$ - set of time values of train set technological processing with z-category on station.

Time, that the cars spend on station, depends on freight flows correspondence capacity and time to process in the station subsystems, and can be described as

$$t_{tr_i}=f_2\left(N_pr;N_{tr};N_{trpr};\{t_{tex}^{z}\}\right)$$

$$t_{pr_i}=f_3\left(M_g;M_{vf};k_n;N_{tr};N_{trpr};\{t_{tex}^{z}\}\right)$$

$$t_{acc_l}^{i}=f_4\left(n_l;k_n;m_l;t_{pr_l};I;m_{gr_l};m_{z.gr_l};\pm\Delta m_l\right)$$

where t_{tr_i} - time is spent on i-station by car without processing, hours;

t_{pr_i} - time is spent on i-station by car with processing (not include wait time in sorting yard), hours;

$t_{acc_l}^{i}$ - wait time of l-address on i-station, hours;

N_pr - train number, that should be processed on station, trains;

n_l - l-address capacity, cars;

m_l - car number in train set with l-address, cars;

t_{pr_l} - gap time while train set with l-address accumulates, hours;

I - arrival interval of trains, that should be processed on station, minutes;

m_{gr_l} - car number in group with l-address, in train to break up on station, cars;

$m_{z.gr_l}$ - car number in closing group in train set with l-address, cars;

$\pm\Delta m_l$ - tolerances in car quantity of train set with l-address, cars.

Depending on the conditions of traffic formation the set of nodes $\{S_i\}$ can be divided into source nodes $\{S_{s_i}\}$ (mostly it is freight stations) and process nodes $\{S_{pr_i}\}$ (marshalling and district stations). On nodes Si the district trains, connected trains and shipper routes can be built. On nodes S_{pr_i} almost all kinds of trains can be built.

The traveling time of train between neighboring stations t_{ij}^G is the composed function of total train traffic on district N_{ij}, that depends on car traffic n_{ij}, district speed V_{ij}^{distr}, length train district L_{ij}^{distr}, district cash throughput capacity N_{ij}^{cash}, district equipment safety φ_{ij}^{tex}, strict compliance with schedule on this district φ_{ij}^{sch}

$$t_{ij}^G = t_{ij}\left(N_{ij}; n_{ij}; V_{ij}^{distr}; L_{ij}^{distr}; N_{ij}^{cash}; \varphi_{ij}^{tex}; \varphi_{ij}^{sch}\right)$$

Control object is the car traffic with certain logistic characteristics and receiving stations, that should be composed to train in accordance with train form plan. Conditions of train forming from the cars is defined by the station's resources (train locomotives, shunting locomotives, yards, and others) and by imposed technological restrictions (train length and weight for addresses, train schedule, and others).

Car traffic can be defined as matrix

$$n = \|n_{ij}\|; n_{ij} > 0; i, j = \overline{1, p}$$

where i – source station and j – destination station (receiving station).

For the control purposes car traffic should be decomposed in accordance with logistic characteristics. **Car traffic's logistic characteristics** are defined by:

- the structure of original freight traffic, that should be moved by the cars from the production point to the point of consumption;
- car traffic's characteristics;
- original car traffic's state;
- car traffic's transportation mode.

Depending on the **structure** of original freight traffic it can be picked out following signs of decomposition, that affect conditions car traffic's handling and processing:

- kind of freight – defines order of maintenance and commercial inspection of cars on station, car traffic conditions of processing on the yard, order of making up cars to trains;
- delivery speed – imposes on the making up variants time restrictions (timely delivery of goods);
- safety necessity – imposes requirements in militarized security while performed cargo delivery process.

IV. Conclusion

Transportation process management aims to achieve the optimal adjusted time and cost values for car's processing on stations and handling a determined car traffic through the considered polygon. Of course, presented in the article object model of transportation process management is simplified and does not solve all emerged operational tasks. However, its main advantage is the scalability and consistency. In the development of the field of research "intelligent management of transportation process in railway transport" object model will be expanded, both due to the emergence of new objects, and due to the detail of existing objects functions.

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ИНТЕЛЛЕКТУАЛЬНОЕ УПРАВЛЕНИЕ ПЕРЕВОЗОЧНЫМ ПРОЦЕССОМ НА ЖЕЛЕЗНОДОРОЖНОМ ТРАНСПОРТЕ: ОБЪЕКТНАЯ МОДЕЛЬ

Ерофеев А.А., Ерофеева Е.А.

Рассмотрены особенности организации перевозочного процесса на железнодорожном транспорте как объекта интеллектуального управления. Проанализирован и систематизирован зарубежный опыт разработки и внедрения интеллектуальных систем управления на железнодорожном транспорте. Установлено, что в железнодорожном транспорте, как системе можно выделить организационную, функциональную и элементную сущности. Определены базовые элементы семиотической модели «железнодорожный транспорт» и сформулированы принципы описания объектной среды. Предложено описывать железнодорожную сеть с использованием математического аппарата теории графив, а в качестве объекта управления рассматривать вагонопотоки с определенными логистическими характеристиками и станциями назначения, которые в соответствии с планом формирования объединяются в поезда.