Information and Computing System for Planning of Management of Railway Stations of Industrial Enterprises

Tatyana Nechai
Department of the Information Technologies and Systems
Penza State Technological University
Penza, Russia
tanyanechay@bk.ru

Gennady Korop
Department of the Information and Computing Systems
Lugansk National University named after Taras Shevchenko
Lugansk, Ukraine
korop_g@mail.ru

Vladimir Roganov
Department of the Information Technologies and Systems
Penza State Technological University
Penza, Russia
vladimir_roganov@mail.ru

Elvira Roganova
Department of the Information and Computing Systems
Penza State University Architecture and Construction
Penza, Russia
roganelka@mail.ru

Marina Chirkina
Department of the Information and Computing Systems
Penza State University Architecture and Construction
Penza, Russia
chm-77@mail.ru

Abstract—**The article deals with the problem of constructing a mathematical model for the optimal organization of information management when planning shunting work at railway stations owned by enterprises. Analysis of the known solutions of this problem showed that the main directions in which optimization should be performed are: taking into account the radii and curvature of the railroad rails on certain sections; accounting for the dependence of fuel consumption by shunting locomotives when performing shunting movements in one direction, in the presence of time reserves; the choice of the route of the train depending on its length, the required number of transfers of arrows, given speed limits, on certain sections of the railway, and a given time of movement of the train. The place of the system for collecting, storing and processing information about the indicators describing the results of shunting control in the general structure of the information system is shown. In the mathematical model on the basis of which a specialized information and computing system is created, all elements and factors affecting the main indicators of its economic efficiency are taken into account.**

Keywords—traffic optimization at railway stations of industrial enterprises

I. INTRODUCTION

The technology of operational planning of shunting work at railway stations of industrial enterprises consists in building a daily work access schedule. This schedule links the work of the railway shop with the railway station of an industrial enterprise. The result of operational planning is the supply of the required number of wagons with raw materials, and sending finished products from the warehouse within 24 hours. The supply of railway cars for unloading and loading should be as uniform as possible during the day and take into account the processing capacity of cargo mechanisms with minimal time spent on maintenance of railway cars.

Daily schedules of the station of an industrial enterprise are drawn up to ensure prompt maintenance of industrial hub enterprises. This takes into account the technological and technical capabilities of the transport system of an industrial enterprise. Based on the daily schedule, the indicators for the use of wagons, loading and unloading devices and locomotives are determined.

For large and medium-sized industrial enterprises with access roads, there is a lack of a clear daily plan for cargo and shunting work. This is due to the fact that there is no common information-structural system, which contains all the necessary information. There are also no mechanisms for the rapid collection and updating of this information. With the development of computer and information management systems, more attention was paid to solving this task [1], attempts were made to computerize and automate many processes, but a common integrated system has not yet been created [2]. The state trunk railway transport, where the development of automated operational planning systems has been engaged for more than 50 years, has good results, but they cannot be used due to the specific working conditions of

railway stations owned by industrial enterprises. Let us consider in more detail the control system of railway stations of industrial enterprises in order to develop a specialized computing system optimizing the movement of trains at railway stations of industrial enterprises.

II. MATERIALS AND METHODS

To date, there are studies in the field of shunting work, which partially optimize it at various stages, which can be reflected in the following categories:

- rationing by analyzing statistical data and adjusting the existing analytical calculation methods [3,4];

- optimization related to fuel economy during maneuvers [5];

- optimization of shunting methods [6,7], such as reducing the number of shunting one-way traffic [8,9] during sorting work with a different number of available ways [10,11].

Often, savings in shunting work can be achieved as a result of evaluating the performance of an enterprise based on a study of specific solutions. For example, laying additional tracks, turning a shunting locomotive to improve visibility and speed up work during maneuvers [12], replacing existing locomotives with more suitable power for specific conditions and so on.

Currently, the implementation of various transport processes is carried out by the collectives of the DNTC (for example, the MoveRW program [13] and simulation simulators based on a PC), the DVGUPS team (the ISKRA program, the ERA [14]), 1C LLC (the "Railway transportations ", intended for simplification of activity of the enterprise in the field of a freight transportation on a railway transportation [15]), UkrGUZHD, etc.

One of the most effective at the moment software products for the railway industrial transport in the field of planning automation and operational management are software products developed by ITL Consulting, in particular, such developments as "Ctrl + Wagon", "Railway Dispatcher" and "IS UZHDP'[16].

The "Ctrl + Wagon" software product is a technological information system for managing industrial railway transport in a limited area;

- Software "Railway Dispatcher" allows you to receive data on the location of cars, their technical condition, data on contracts with customers;

- the software package "IS UZHDP" (Integrated Rail Traffic Management System) automates the workflow, processes the primary information from the automated management system, and allows you to apply an electronic digital signature to exchange information between the company and Russian Railways [16].

The general information and structural system for railway stations of industrial enterprises was tried to be presented and described in their works by Korop, etc. [5]. They showed that

it is necessary to investigate shunting work, as this includes all movements on the daily schedule.

For long-haul transport, shunting work has been well studied, especially work on a sorting hill. However, the available analytical methods of calculation and derived standard data are not effective enough for industrial railway transport due to its specific features. Enterprises have a very extensive railway network, which uses low-power locomotives. Most shunting operations are carried out on sections of roads with curves of small radii and steep inclines, which imposes restrictions both on speed and on the number of cars being moved along these routes. The disbanding of trains may be carried out on non-profiled railway tracks due to the lack of marshalling railway tracks.

Therefore, we need a mechanism for the daily schedule of the schedule taking into account:

1) slopes, profiles, lengths, in general, the structure of the ground.

2) formation of route options

Methods for automating operational planning in industrial railway transport by automating the construction of a daily schedule plan are presented in the work of G. Korop. Also in further studies of this author an ergatic system is proposed, in which the operator interactively builds a schedule [5]. The paper proposes an algorithm for finding solutions on the optimal sequence of cleaning cars from cargo fronts to the plant station. This algorithm was intended as a decision support tool for use in automated systems for constructing a daily schedule of the schedule (Fig. 1).

Fig. 1. Diagram of relations between bols of the information-planning system of a industrial transport enterprise

However, in this task it is impossible to apply the known solutions applicable on the main railway transport and stations of the main roads.

The main differences of shunting work on industrial transport:

- the prevalence of shunting operations associated with the supply and cleaning of cars;

- disbanding trains on non-core railway;

- lack of a sufficient number of sorting methods;

- different types of locomotives;

- complex track development network railway;

- manual translation of railway arrows by a locomotive brigade member;

- the use of low-power locomotives;

- short distance shunting one-way movements;

- low speed of a locomotives motion;

- a significant number of sections of the road with curves of small radii and steep inclines;

- a small number of centralized switches.

Therefore, the solution of the task of automating planning, rationing and modeling of shunting work is relevant, as the development of a subsystem in a larger project is the creation of a common system for planning and managing industrial transport in industrial enterprises.

The creation of a decision support system in the conduct of shunting work and an automated apparatus for obtaining a plan and a time for performing shunting work based on real and accurate calculations is a relevant research topic. This will give a new impetus to the development of this industry, as well as open up opportunities to optimize and improve this process, which will in turn bring economic benefits, which is so necessary in modern conditions.

In the analysis of key factors affecting the efficiency of shunting work, the following tasks were highlighted:

- finding the optimal route for the shunting train;

- simulation of the movement of the shunting structure, taking into account the radii, slopes of the tracks, speed limits on the sections;

- chossing the optimal schedule of the shunting train;

- reduction of time and financial costs for carrying out shunting work.

Analysis of the known solutions [17] showed that it is advisable to use technological maps of shunting work in the form of tables, where all performed technological operations are described in detail.

The developed software package as a final result should provide the schedules and performed traction calculations.

The main modules of such software package are the following: the editor of the properties of the access road and stations, the editor of the scheme of the access road and stations, the module for finding the routes (Fig. 2).
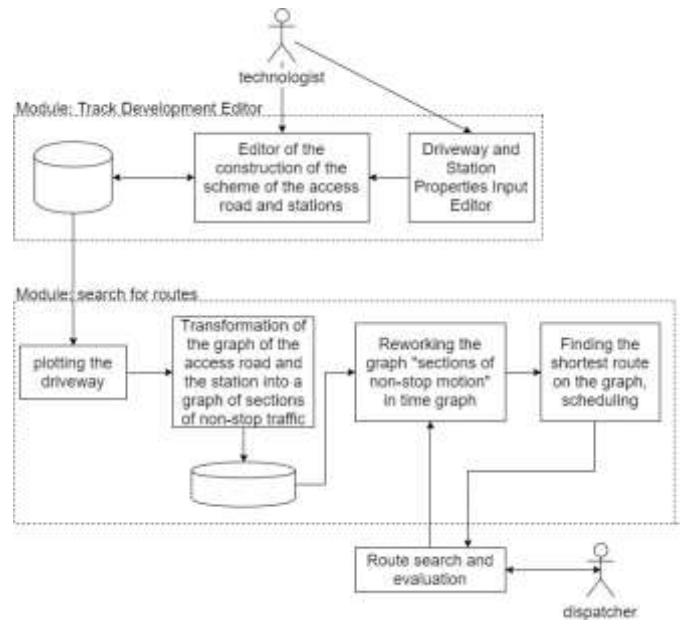
Fig. 2. A generalized scheme of the work of the modules for the construction of the "editor of the development of railway tracks" and "the search for optimal routes of movement of trains".

The schedule of railway tracks of the station is drawn in a specialized editor, all characteristics are entered. In the module of railway routes, on the basis of the information model, a graph of the development of railway tracks is constructed, which is converted into a graph from sections of non-stop movement of the train. Using calculations, the graph of non-stop traffic routes is converted into a time graph.

The principle of finding the time of shunting work is described in [19]. The main stages include:

1. Work with the interface is as follows [20]. First, the expert user must indicate whether there is a time reserve [21]. Then, in the modular window, manually choose a shunting train that will follow the route [22]. Next, set the starting and ending point of the route. Then the number of wagons for uncoupling is indicated, or if the wagons are already located on this path, then the number of wagons [23]. The following one-way traffic and the release / hitching option is set in the same way. At the end, the user clicks the "Done" button and waits for the result.

2. After setting all initial and final points, an algorithm is launched to form a graph of routes of movement of the shunting train [13]. The algorithm takes into account the presence of railroad switches and their position between the starting and ending point of each one-way traffic.

3. The algorithm finds routes of non-stop motion and recalculates the length of one-way traffic [23]. Information about each direction of the one-way locomotive, the number of railway cars and their characteristics enters the traction calculation unit, where using the modified method, the travel time is calculated along specified routes.

4. 4. Further, from the obtained variants of the movement time, a time graph is formed, on the basis of which the optimal variant of the movement of the shunting train is selected.

5. According to the existing plan for the implementation of shunting work, taking into account the routes of movement, data on additional operations and their time are pulled from the block for determining additional operations between one-way traffic. The time of additional operations is regulated and taken from the regulatory framework. As a result, information is displayed in the form of a technological map.

6. A special role in the system is occupied by the optimization of the information-computing system using neural networks, which is trained on the results of calculations obtained using the modified traction calculation method. In the future, the neural network unit traction calculations.

The algorithm for performing shunting work depends on the availability of a time reserve. If there is a reserve of time ($R_t > 0$), then the system searches for a variant of shunting control according to the criterion of minimizing fuel consumption, otherwise ($R_t = 0$) – the system searches for a variant of controlling shunting work, which must be done in the shortest time:

$$f_1(X_1) = \begin{cases} S_t \times X_1, R_t = 0 \\ S_g \times X_1, R_t > 0 \end{cases} \to \min , \qquad (1)$$

where $f_1(X_1)$ is the loss function S_t – the cost in terms of time losses from loading / unloading the train,

S_g – cost of the work of the locomotive, tied to the flow time of shunting operations,

X_1 – time spent on loading / unloading of the train.

In general, the time of shunting work is according to the formula:

$$X_1 = \sum_{i=1}^{n} (t_{i-\Delta t} + t_{i+\Delta t}) , \qquad (2)$$

where $t_{i-\Delta t}$ is the time of the *i*-th shunting one-way traffic (in minutes);

$t_{i+\Delta t}$ – the time spent on additional operations when performing the *i*-th shunting one-way traffic (in minutes) is determined in accordance with current regulations; *i* is the number of one-way movements, $i = 1..n, n > 0$.

The time of additional operations is taken according to the developed standards and technological process [16].

The time of one-way shunting traffic t_{l_i} is a variable quantity, the calculation of which is proposed to be made taking into account the specific working conditions and the following factors:

$$t_{l_i} = f_2(S_M; L_M; L_i^j; R_p; \gamma_z; \phi; r_k; t_{n_1}^{n_2}) , \qquad (3)$$

$$\begin{cases} L_M < L_i^j , i = 1..n, n > 0 \\ t_{n_1}^{\min} < t_{n_1}^{n_2} , t_{n_1}^{\min} = 3c. \end{cases}$$

where S_M – structure of the composition to be reformed;

L_M – length of the composition, m;

L_i^j – length of the *i*-th segment *j* of the path, m;

R_p – reduced radius;

γ_z – bias;

φ – temperature conditions (heat, cold, wind, dampness);

r_k – driving mode;

$t_{n_1}^{n_2}$ – time of switching from one controller position to the next, sec,

$t_{n_1}^{\min}$ – the minimum time to switch from one position to the next controller (3 seconds).

When $R_t = 0$, formula (3) takes the form:

$$t_{l_i} = f_2(S_M; L_M; L_i^j; R_p; \gamma_z; \phi; r_k^{\max}; t_{n_1}^{n_2}) \to \min \qquad (4)$$

where f_2 – function of the economic costs of moving the composition in one direction

$r_k^{\max}$ – mode of movement of the composition in the maximum position of the controller (with the maximum allowable speed).

When $R_t > 0$, formula (3) takes the form:

$$t_{l_i} = f_2(S_M; L_M; L_i^j; R_p; \gamma_z; \phi; r_k^g; t_{n_1}^{n_2}) \to \min \qquad (5)$$

where r_k^g - mode of movement of the composition with minimal fuel consumption.

Next, we describe the elements that make up the formula (3).

In a computing system, the shunting composition is represented as a data structure:

$$S_M = f_3(D_v, C_m) \qquad (6)$$

where C_m – shunting locomotive;

D_v – list of cars with a shunting locomotive, where each car has its own set of characteristics;

$$D_v = f_4\{d_x^v\} \qquad (7)$$

where d_x^v – many permissible types of railway cars;

x – wagon index.

The task can be solved using graph theory and operations research. With the help of graph theory, the task of describing the available railway tracks is formalized. Using 1-8, a target function and a constraint system are developed. Using the methods of research operations, let us find optimal solution 3,4,5. The high performance of modern hardware and computing systems allows one not only to use the well-known methods of the theory of operations, but also to solve the tasks posed by the method of direct enumeration.

III Conclusion

The principles for improving the planning of shunting work, considered in the article, separately confirmed their effectiveness, which makes it possible to assume that synthesizing them into one whole will give the expected positive effect.

The relevance of the results obtained in the article is confirmed by similar developments in the field of transport in both domestic [17,18] and foreign articles and complexes [6,7,8,10,11], which have been successfully implemented and continue to be implemented.

Field tests showed that as a result of using one of the modules of a specialized computing system, namely "Shunting Routes", the following indicators were achieved:

- decrease in the employment of the dispatcher by 83% when rationing the shunting work on the access roads of the enterprise;

- accuracy of planning the time of the shunting train increased by 18%;

- accuracy of fuel costs rationing increased by 7%;

- time to create an information model increased by 10% from the baseline calculation of 10 min / way;

- time to enter into the system of all possible routes of movement of the composition, with an indication of the change of direction of movement was reduced by 100% based on the experimental standard of 5 minutes to 1 route;

- calculation time of the specialized computing system of the minimum shunting route using a neural network is 14% of the calculation time using the algorithm of the adapted traction calculations.

References

[1] V. Gapanovich, V. Grachev, "Automation systems and information technologies for transportation management on railways," A textbook for universities of railway transport. Moscow: Marshrut. 2006.

[2] T.A. Nechay, Y.V. Puha, A.A. Klyuev, "The use of dynamic programming in planning shunting work at an industrial enterprise", Scientific and technical problems of transport, industry and education, vol. 2, pp. 19-23, 2012.

[3] L. Leimane and O. Nikiforova, "Mapping of Activities for Object-Oriented System Analysis," Applied Computer Systems, Riga, Latvia, vol. 23, No. 1, pp. 5-11, May 2018.

[4] https://elibrary.ru/item.asp?id=25502116 (date of the application: 16.09.2018).

[5] T.Balitskaya, G. Korop, D.Marchenko, V.Kuchma, "The structure of computerbased system of industrial railway traffic scheduling," TEKA. Comission of Motorization and Energetics in Agriculture, Lublin, vol. 13, No 3, pp. 03-08, 2013.

[6] W. van Wezel, "Task oriented support for train shunting planning," People and Rail Systems: Human Factors at the Heart of the Railway. Aldershot : Ashgate, pp. 309-318, 2007.

[7] E. Abbink, "Intelligent shunting: Dealing with constraints (satisfaction)," Planning in Intelligent Systems: Aspects, Motivations, and Methods, pp. 391-414. John Wiley & Sons, 2006.

[8] V.N Balabin, "Investigation of fuel efficiency and modernization of locomotives in industrial enterprises (for example, a diesel locomotive TEM2UM Moscow plant "Stroiplastmass")," Lokomotiv-Inform, vol. 3, pp. 11-13, 2008.

[9] Michael Gatto, Jens Maue, Mat´us Mihal´ak, and Peter Widmayer, "Shunting for dummies: An introductory algorithmic survey", Robust and Online Large-Scale Optimization, Lecture Notes in Computer Science, vol. 5868, pp. 310–337, Springer, Berlin, Heidelberg, 2009.

[10] Tim Nonner, Alexander Souza, "Optimal Algorithms for Train Shunting and Relaxed List Update Problems," ATMOS'12, Vol. 25, pp. 97-107, September 13 2012, OASICS, Ljubljana, Slovenia [12th Workshop on Algorithmic Approaches for Transportation Modelling, Optimization, and Systems (ATMOS'12), p.140, 2012].

[11] Ramon M. Lentink, Pieter-Jan Fioole, Leo G. Kroon, Cor van't. Woudt, "Applying Operations Research techniques to planning of train shunting," chapter 15, Planning in Intelligent Systems (Wiley Interscience), pp. 415-436, Hoboken: Wiley, 2006.

[12] Berkay Beygo, Improvement of Decision Support System for Rail Depot Planning, Master of Science Thesis in the Programme Computer Science: Algorithms, Languages and Logic, Chalmers University of Technology, Gothenburg, Sweden, 2011, 58 p.

[13] http://brailsys.com/MoveRW_0.htm (date of the application: 16.10.2018).

[14] https://sites.google.com/site/isystemgdt/home (date of the application: 16.10.2018).

[15] https://solutions.1c.ru/catalog/tms/features (date of the application: 16.09.2018).

[16] http://www.itlc.ru/ (date of the application: 16.10.2018).

[17] M.Y. Mikheev, V.R. Roganov, P.G. Andreev, N.V. Goryachev, V.A. Trusov, "Developing the structure of the quality control system of power supply units in mobile robots," 2017 International Siberian Conference on Control and Communications, SIBCON 2017 - Proceedings 2017. P. 7998579.

[18] A. Rakhmangulov, A. Kolga, N. Osintcev, I. Stolpovskikh, A. Sladkowski, "Mathematical Model of Optimal Empty Rail Car Distribution at Railway Transport Nodes", Transport Problems, 2014, Volume 9, Issue 3, pp.125-132.

[19] S. V. Panchenko, T. V. Butko, A. V. Prokhorchenko, L. O. Parkhomenko, "Formation of an automated traffic capacity calculation system of rail networks for freight flowsof mining and smelting enterprises," Scientific Bulletin of National Mining University Issue 2, pp. 93-99, 2016.

[20] I. Makarova, R. Khabibullin, E. Belyaev, V. Mavrin, "Increase of City Transport System Management Efficiency with Application of Modeling Methods and Data Intellectual Analysis," Intelligent Transportation Systems – Problems and Perspectives, vol. 32, pp. 37-80, Springer, Cham, 2016.

[21] V. Roganov, M. Miheev, E. Roganova, B. I. Nurgozhin, V. Fillipenko, "Main provisions for formation of cognitive model of visually

observable environment synthesized for aircraft simulator," 2017 Advances in Engineering Research, Vol. 133. Actual Issues of Mechanical Engineering (AIME 2017) pp. 671-676.

[22] V.R. Roganov, E.V. Roganova, M.J. Micheev, , T.V. Zhashkova, O.A. Kuvshinova, S.M. Gushchin, "Flight simulator information support,"

Defence S and T Technical Bulletin, Volume 11, Issue 1, 2018, pp. 90-98.

[23] A. Grigoriev, E. Danilova, V. Trusov, M. Miheev, M. Uhanova, "Modelling of Measurement Error for Vibrational Displacement Based on the Blurring Analysis of a Round Mark Image," Applied Computer Systems. May 2018, vol. 23, no 1, pp. 69-74.