Enhancing the Efficiency of Operational Planning for Local Railway Services through Advanced Planning Methods

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**Abstract.** Operational planning of local railway work plays a critical role in ensuring the overall efficiency and reliability of railway operations. This study explores the development and application of a dynamic modeling approach aimed at enhancing the quality of operational planning at both station and section levels. The proposed model supports real-time forecasting of transport processes and facilitates optimal allocation of operational resources. Building on this framework, a methodology is introduced for improving risk assessment and increasing the accuracy of operational performance metrics. The paper also provides a critical analysis of current shortcomings in existing planning systems and discusses practical considerations for implementing the proposed solutions. The findings of this research can be applied to improve operational planning systems, thereby increasing the resilience and efficiency of railway operations.

**Keywords:** Operational planning, local railway work, dynamic modeling, real-time forecasting, resource allocation, risk assessment, performance metrics, planning systems, railway efficiency, system resilience

# INTRODUCTION

Operational planning of local railway work is a vital component of managing the transportation process. This process is implemented through a multi-level railway dispatching system, and its efficiency depends on the technology used, the prevailing operating conditions, and the adoption of innovations.

High-quality solutions to operational planning tasks for local work are ensured by using models that help reduce information uncertainty in decision-making systems. This is achieved through timely and accurate forecasting of the states of monitored objects. Such models are based on advanced information technologies that enable real-time monitoring and evaluation of transportation process parameters. As a result, resources are utilized more rationally, and transportation performance indicators improve [1].

Local work constitutes an integral part of the transportation process, primarily considered at the levels of railway stations, sections, and hubs. These entities are conditionally autonomous and can form a railway network of arbitrary size for research purposes.

On railways, local work is performed during the initial and final phases of cargo delivery. The results of this work substantially affect train accumulation and formation processes, which, in turn, influence the operational performance indicators of the entire railway system.

The tasks involved in organizing local work are multifactorial and difficult to formalize. Therefore, improving the quality of operational planning for local work can be achieved through enhanced scientific approaches and methodological frameworks, as well as through the development and implementation of organizational, technological, and informational solutions based on these foundations.

Railways in developed countries devote considerable attention to the organization, planning, and management of local work [2, 3, 4]. Scientific and practical tasks in this field are addressed in the following primary directions:

- integrating local work into cargo delivery logistics chains;

- concentrating cargo operations within the railway network;

- developing efficient and well-founded methods for organizing the delivery of local wagons;

- dispatching, digitalization, and intelligent technologies in local work management systems.

Focusing on dispatching and digitalization, this study aims to enhance the quality of operational planning for local railway work. The first stage involves creating a specialized dynamic model of the transportation process using information systems currently employed by Belarusian Railways. In the second stage, a new methodology for operational planning of local work is developed using this dynamic model, allowing for more accurate results and risk forecasting [1, 20].

# DYNAMIC MODEL OF THE TRANSPORTATION PROCESS

Improving the quality of operational planning for local work can be achieved by employing analytical models that describe temporal changes (dynamics) in wagon parameters within the railway network.

Dynamic models represent structures that reflect changes in the state of the studied object over time. In this study, the dynamic model *W*(*t*) is understood as a set of objects and their properties that change over time. This enables parameter forecasting for the transportation process based on formal rules describing interactions among the model's objects. The magnitude and dynamics of these parameters are subsequently used to address operational planning tasks for local railway work.

A prerequisite for developing a dynamic model of the transportation process is the availability of information arrays that sequentially reflect changes in the transportation process. High reliability of modeling is required, characterized by informativeness, accessibility, sufficiency, representativeness, relevance, timeliness, accuracy, and reliability of the data [1, 5].

The information environment for the dynamic model of the transportation process consists of:

- conditionally constant information, including an information model of railway infrastructure objects, regulatory data, and mathematical tools for model operation;

- variable information, reflecting the states of dynamic railway transport objects for transportation process forecasting and applying results in operational planning of local work.

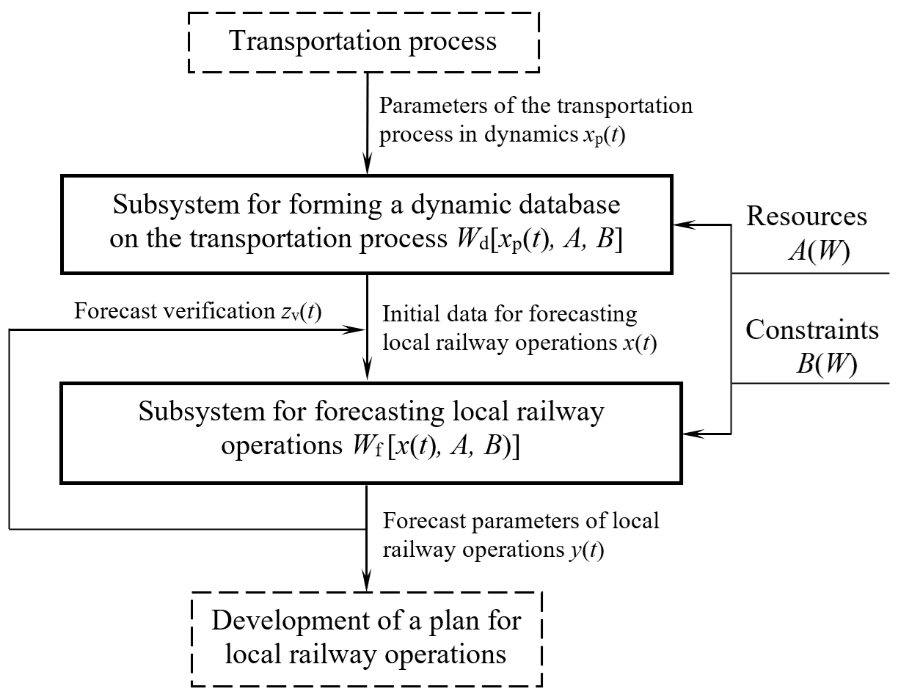
The dynamic model of the transportation process must adhere to the following conditions:

- universality of approaches for modeling the states of technological processes in local work, applicable to various railway network configurations;

- feasibility of automated implementation of the developed algorithms during operational planning;

- adaptability of automated solutions within existing railway information systems, maximizing the use of existing databases, software, and hardware resources.

The proposed dynamic model concept for solving operational planning tasks in local railway work is illustrated in Fig.1 [1, 16].



**FIGURE 1.** Concept of the proposed dynamic model

The input discrete stream for the dynamic model *x*p(*t*) comprises registered and accumulated data on the state of the transportation process within the operational information zone. This zone includes a calculated railway section or node and the adjacent railway network, within the boundaries where the influence of dynamic objects (trains, wagons) on the transportation process at the calculated area can be assessed.

In the subsystem for forming the dynamic database *W*d[*x*p(*t*), *A*, *B*], the state of the transportation process within the operational information zone is reflected. This database includes numerous parameters required for planning local work, organized by time, infrastructure objects, and dynamic objects.

The initial data for forecasting the transportation process *x*(*t*) represent an ordered selection of parameters from the database *W*d[*x*p(*t*), *A*, *B*], which describe the transportation process within the operational information zone. These data must be sufficient to enable forecasting of the transportation process with a given reliability *p*[*W*(*t*)].

The transportation process forecasting subsystem *W*f[*x*p(*t*), *A*, *B*] includes informational and analytical models. It employs a set of algorithms to calculate transportation process parameters for any moment within the forecast period. In this subsystem, conditionally constant information encompasses mathematical model components and formalized configurations of infrastructure objects within the operational information zone, production resources, and regulatory information necessary for defining model object characteristics by their identifiers.

The output flow *y*(*t*) from the dynamic model comprises structured data on the sequential changes in transportation process parameters (model objects) over the forecast period. Ordered data arrays from *y*(*t*), divided by infrastructure objects and individual dynamic objects, are used as input for establishing transportation process norms.

Verification results *z*v(*t*) allow dispatchers to modify the input flow *x*(*t*) if the forecasting results *y*(*t*) are deemed unsatisfactory under predefined constraints *B*(*W*).

Resources *A*(*W*) ensure the operability and functionality of the model. These resources include computing equipment, data transmission channels, external information systems, transportation process modeling procedures and software environments, and operational personnel.

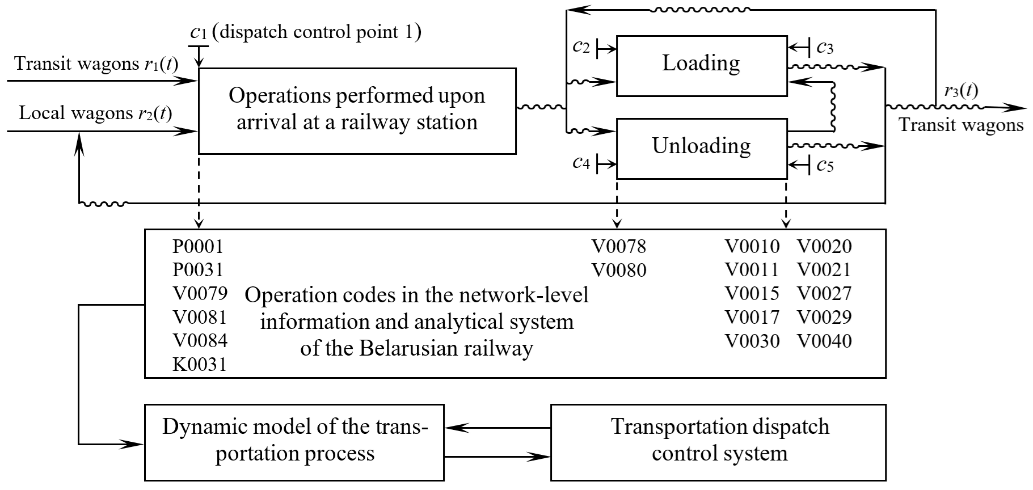
Constraints *B*(*W*) define the permissible range of input data *x*p(*t*), *x*(*t*) and transportation process modeling results *y*(*t*).

Dynamic model objects *W*(*t*) are interconnected with flows *x*p(*t*), *x*(*t*), *y*(*t*), *z*v(*t*) and subsystems *W*d, *W*f ​. The primary objects are as follows:

- railway infrastructure objects *W*s: sections, stations and their subsystems, terminals;

- dynamic objects *W*d(*t*): wagons, containers, cargos, locomotives [1, 18].

Fig. 2 illustrates the functional scheme of the proposed dynamic model of the transportation process using Belarusian Railways as an example.



**FIGURE 2.** Functional scheme of the dynamic model

The proposed dynamic model of the transportation process serves as the foundation for comprehensive, automated real-time planning of local work. It enables addressing current issues using existing information-analytical systems for managing transportation processes in railway transport.

# METHODOLOGY FOR OPERATIONAL PLANNING OF LOCAL WORK

The plan for local work within the transportation management system is a critical organizational element. It is interlinked with the train and freight operation plans of the railway and includes specific indicators and planning assignments that characterize both train operations (e.g., plans for dispatching local trains and regulating empty wagons) and freight operations (e.g., wagon loading and unloading) [1, 6, 11, 13].

The existing system for operational planning of local work has several drawbacks (using Belarusian Railways as an example):

- in automated planning of freight operations, the lack of sufficient information leads to a high reliance on expert decisions, introducing risks of unreliable results;

- the system lacks accurate models for forecasting the completion of freight operations with wagons;

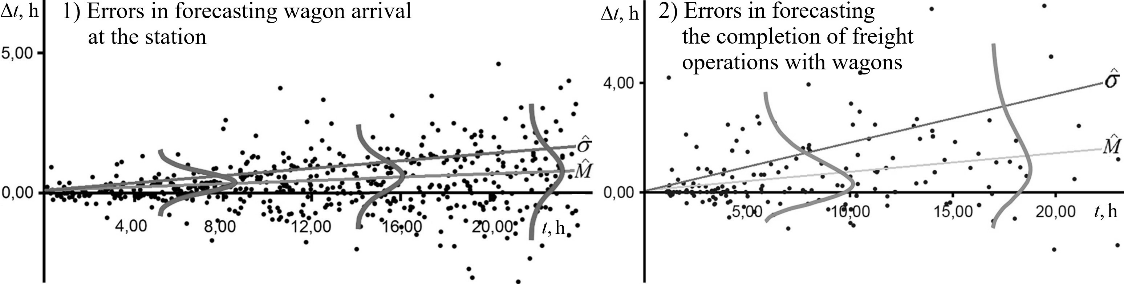
- the capabilities of modern information systems for planning train formation across the railway network are underutilized in the planning process for local work.

To address these shortcomings, the automated planning process for local railway work is proposed to operate at the intersection of two models:

1) a model for calculating the arrival time of each wagon at a technical station serving local operations within the considered railway area;

2) a model for the operation of loading and unloading facilities for wagons within the same area.

Information-analytical systems currently used in railway transport exhibit forecasting errors when predicting wagon arrival times at stations (model 1) and the completion times of freight operations with wagons (model 2). It is proposed that these errors be analyzed and accounted for during operational planning (Fig. 3) [1, 6, 12, 14].



**FIGURE 3.** Analysis of errors (residuals) in predictive models

Fig. 3 illustrates the study of the distribution of deviations (forecast residuals) in models used by Belarusian Railways for calculating wagon arrival times at stations within trains and the completion of freight operations with wagons. The analysis revealed signs of heteroscedasticity in both cases [7, 8, 15, 17]. As a result, pairs of linearly increasing corrections over time Δ*t*i for the expected value and the standard deviation of the error (0.03*t*; 0.05*t*) and (0.07*t*; 0.11*t*), can be applied on Belarusian Railways to adjust forecasts.

Numerical characteristics of deviations in the expected value of the error can be used to improve forecasting accuracy. Time-varying standard deviation characteristics are proposed for calculating the following risks:

- exceeding the established cargo delivery time.

- exceeding the contractual time for providing empty wagons for loading.

- exceeding the allowable time for railway use of wagons under agreements with rolling stock operators [9, 16].

The basis for calculating these risks is the probability distribution of wagons across arriving and departing trains. This ensures that predictions account for the fact that wagons may be in various trains with certain probabilities. Consequently, train compositions in the dynamic model can be considered as fuzzy sets [10, 18, 20]. This approach provides additional opportunities to improve the local railway work plan. The plan can include additional useful parameters. For instance, for a classification yard, the following may be analyzed during the evaluation of a local work plan:

- the expected number of wagons ready for dispatch in a train serving local operations in the adjoining section;

- the number and identification of wagons with a dispatch probability of *p*≥ 0.5 in a particular train;

- the estimated probability of exceeding technical constraints on the number of wagons in a train or its mass for the specified locomotive type [1, 19].

It should be noted that modern computational platforms allow for the calculation of these characteristics within acceptable timeframes.

# CONCLUSION

The article presents the concept of a dynamic model of the transportation process and identifies and describes its main objects and system connections. The integration of this dynamic model into the transportation dispatch management system will contribute to the rational use of resources, risk reduction, and improved performance in managing wagons and locomotives.

The dynamic model leverages existing information systems, eliminating the need for additional efforts in integration or algorithm modification.

The proposed methodology, along with the scientific and practical solutions obtained, enhances the reliability of operational planning results for local railway work. The methodology is scalable for objects and tasks in operational planning and can be applied to other areas of railway transportation planning. Specifically, it can address pressing issues in drafting departure plans for freight trains of all categories at stations.

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