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RESEARCH OF TRAFFIC PREDICTION ACCURACY INFLUENCE ON THE EFFECTIVENESS OF TRAINS BREAKING-UP ORDER CONTROL

Summary. The article presents the research results of economic feasibility of trains' breaking-up order control at marshalling yards. The article objective was to determine the area of rational use of trains' breaking-up order model, formalized in the form of stochastic programming problem. As a effectiveness criterion of trains' breaking-up order operating costs of marshalling yard were used, including the costs associated with cars' and locomotives' dwell time on the station and its approaches, as well as costs associated with additional shunting work. With the help of simulation modeling the dependence was obtained, describing the impact of trains' arrival forecasting error and processed car volumes on reducing operating costs of the marshalling yards through the trains' breaking-up order control. The studies enable us to establish the requirements for the accuracy of information support of operational planning tasks, which is necessary to achieve the desired economic effect of the trains' breaking-up order control.

1. INTRODUCTION

Passing cars through the classification yards as quickly as possible remains a primary mean of reducing dwell times and increasing yard efficiency. Various yard automation and control systems have been developed to assist in the implementation of these aims [1]. For example, BNSF Railway managers use Innovative Railroad Blocking Optimizer to plan train builds, and Canadian Pacific Railway also plans to begin using an electronic tool to more accurately plan a train consist before cars reach a yard [2].

According to findings [3], the yardmaster is a bottleneck in most of the classification yards. Thus, investigation of automated yardmaster decision support systems is an actual challenge. Next-generation yard control systems would improve the coordination and hand-off between terminal and mainline operations; such systems would facilitate a more efficient and prioritized movement of cars from the receiving yard to the classification hump process [4]. Trains breaking-up order control (TBOC) at classification yards is one of the influence means on the train formation processes. The TBOC's expediency was justified in [5–6]: "the humping process should be subordinate to the pull-down process because the latter is the principal bottleneck in many yards. The hump should be managed and operated so that it provides the bottleneck exactly what it needs, when it needs it."

At the present time, TBOC is almost never used by operational staff, due to the complexity of the task, as well as lack of appropriate automated systems for its solving. In addition, the ability to effectively control trains' breaking-up order largely depends on the quality of information management, among which train arrival forecast plays a particularly important role. Thus, two necessary conditions for practical application of tasks of trains' breaking-up order selection are imposing this feature on computerized systems of control and providing these systems with reliable and accurate forecast of the trains' arrival.

2. LITERATURE REVIEW AND DEFINING THE PROBLEM

The papers of many scientists are dedicated to the development of automated decision support systems of operational staff. The possibility of creating the systems on the basis of the theory of fuzzy sets and fuzzy logic was considered in paper [7]. Paper [8] is a logical continuation of the scientific research that proposed the usage of the artificial neural network elements for creating decision support systems.

In paper [9] the hump sequencing component of the Terminal Priority Movement Planner was described, a proof-of-concept decision support system, field tested in 1994 at Union Pacific Railroad's Hinkle, Oregon, classification yard. In papers [10, 11, 17] a hump sequence optimization model was proposed, which takes hump sequence and assemble sequence into consideration: "the hump sequence and assemble sequence are interacted, and the capacity must be coordination between those two parts. The efforts on the efficiency of the whole dispatching system appears insignificant, if only the hump capacity or assemble capacity is increased."

Practical works of the implementation of station processes automated control systems should take into account a certain unreliability of the trains' arrival prediction. The trains' breaking-up order control model that takes into account the stochastic nature of forecasting their arrival at the station was described in paper [12]. However, even a stochastic model may prove to be ineffective in the absence of reliable information about the trains' arrival. The accuracy of traffic forecasting is one of the main factors determining the appropriateness of trains' breaking-up order control.

The main positive effect of changes in the trains' breaking-up order control is achieved by reducing unproductive dwell time of cars at the station breaking-up subsystem. The latter usually occurs in the case of processed car volumes and breaking-up subsystem loading level increasing.

Thus, the area of effective control of the trains' breaking-up order is determined primarily by two factors – accuracy of traffic forecasting and size of car processing. The task of determining this area is important and was solved in this paper.

3. RESEARCH OF ECONOMIC EFFICIENCY OF TRAINS BREAKING-UP ORDER CONTROL

In the railways of Ukraine, a freight production system is used, based on compliance with the conditions of strictly defined train weight and train length standards – that is, the formation of the train in the classification yard can be carried out only in case of accumulation of cars compound satisfying these conditions. With this work technology, completion of the cars compounds accumulation as early as possible and their early departure from the station is the most desirable aim to solve most train formations (that include TBOC).

Initial data for scheduling trains' formation and trains' departure are as follows:

– car list of each train (excluding local, pick-up, and transfer ones) arriving for full or partial processing;
– plan of trains' arrival to the station;
– data on presence at the station tracks of trains and cars according formation plan at the beginning of planning period;
– data on availability and expected arrival of locomotives and locomotive crews for trains' departure;
– data on the quantity, destination, and estimated time of car, which are rearranged to the station track after the cargo handling operations;
– technological time standards for operations with trains and cars.

A planning operator provides calculation of operational plans of train formation of 4-6-hour period. The operator receives data on the quantity, destination, and planned rearrangement time of local cars to the station track from shunting dispatcher.

Calculation of the train formation, which is the estimation of moments of trains' departure preparedness, is determined on the basis of established technological time standards of trains' presence at the receiving and departure yards, trains' breaking-up, their formation, and rearrangement to the departure yard.

After train formation plan calculation (based on the accepted breaking-up order), the operator informs the station (shunting) dispatcher the expected time of trains' formation completion.

Afterward, the shunting dispatcher determines the procedure of preparing formed trains for departure. During trains' departure planning, number-specific assignment of own formation and transit trains according schedule train path is carried out. At this time the train number, its departure, destination station, and locomotive number are indicated. In some cases, when the number of schedule train path of planning period is less than the number of planned departure trains, the departure of additional trains is performed according the dispatch schedule. In practice, the proportion of the trains that departure according to the dispatch schedule reaches up to 50%.

Nowadays, train formation planning is performed "in manual mode". Given the large amount of information that must be processed in a short time, economically feasible decision making by the operational staff is an extremely difficult task. Automated systems can facilitate decision-making procedures and improve trains' breaking-up order control.

The automated control system (ACS) of trains' breaking-up order should be based on a reliable forecast of trains' arrival. Now, the Ukrainian automated control system ACS VP UZ-E contains the information only about performed railway traffic. Thus, the operating staff can receive the actual points of trains' arrival, departure, or passing the stations. At that, ACS VP UZ-E does not provide railway traffic forecasting. Therefore, during current planning of stations, work operational staff, based on normative duration of the trains' movement between stations and on own experience, can only manually specify the expected time of trains' arrival. Despite the fact that often the accuracy of the forecasting can be quite high (average forecasting error can be no more than 5-10 minutes), the lack of this information in the automated control systems greatly complicates the possibility of its use for solving complex optimization control problems.

The absence of automated trains' traffic forecasting in ACS VP UZ-E complicates the use of many levers of influence on train formation processes by the operational staff, including control of trains' breaking-up order.

To ensure the forecast reliability, the traffic forecasting system should be based on modern mathematical and technical means. Mathematical tool of artificial neural networks is a powerful mean for creating forecasting models. The possibilities of its application for train traffic forecasting are investigated in the paper [13], which proposed to perform predictions based on consideration of a wide range of factors that affect the conditions of trains' movement.

Since even the most reliable forecast is characterized by some random error, it is important to know how accurate should be the forecast in order to provide an effective TBOC. In other words, it is necessary to determine how the efficacy of this task implementation changes by changing the characteristics of stochastic forecasting error.

The random value of forecasting error for sufficiently adequate and reliable forecasting model is described using normal distribution with zero expectation and a certain standard deviation, depending on the traffic conditions at railway lines. This view is confirmed by studies [14], performed at DNURT. Therefore, the study of trains' breaking-up order control efficiency in this paper was made based on the assumption that the random value of forecasting error is described by normal distribution with expectation zero. This random value is determined by the standard deviation.

For research the model TBOC presented in [15] was used. Each option of train processing is characterized by selected trains' breaking-up order

$$X^{(t)} = \{N_1, N_2, \ldots, N_k\}, \tag{1}$$

where: $N_1, N_2, ..., N_k$ – train number, which is breaking-up, respectively, first, second, k;

t – number of trains breaking-up order, $t = 1...k!$

Let's consider the breaking-up of one train as one step of the task. In equation (1) there is restriction of the trains' quantity that can be considered in the step of solving the problem:

$$k \le h, \tag{2}$$

where: h – the number of tracks in receiving yard of marshalling station.

We denote the whole set of options of the trains breaking-up as $X = \{X^{(t)}\}$. Among all the options $X^{(t)}$ it is necessary to select the one that provides the minimum overall operating costs of marshalling station. In this case, the objective function of the TBOC task is formulated as follows:

$$C(X^{(t)}) = C_{wh}(X^{(t)}) + C_{th}(X^{(t)}) + C_{lh}(X^{(t)}) + C_{man}(X^{(t)}) \longrightarrow \min_{\forall X^{(t)} \in X}, \tag{3}$$

where: $C_{wh}(X^{(t)})$ – costs associated with dwell time of cars at the station in the implementation of the breaking-up order $X^{(t)}$; these costs are determined in currency units on the basis of the cars' total dwell time and the cost of one hour of car dwell time at the station. These costs take into account the time spent by cars at the whole station from arrival (for actually arrived cars – from the current time) to the departure from the station;

$C_{th}(X^{(t)})$ – costs associated with dwell time of trains in case of impossibility of their receiving at station in the implementation of breaking-up order $X^{(t)}$; these costs are determined in currency units as the sum of the costs of cars' and locomotives' dwell time and locomotive crews wages (these costs take into account the time spent prior to arrival);

$C_{lh}(X^{(t)})$ – costs associated with dwell time of locomotives at the station in the implementation of breaking-up order $X^{(t)}$; these costs are determined in currency units as the sum of the direct costs of downtime of train locomotives and locomotive crews wages (these costs take into account the time spent after arrival);

$C_{man}(X^{(t)})$ – costs associated with additional shunting on station in the implementation of breaking-up order (this part of the costs arise, for example, during overflow of sorting tracks); these costs are determined in currency units as the sum of the cost of shunting locomotives' dwell time, the cost of energy spent on the performance of shunting operations, and locomotive crews' wages.

The result of trains' breaking-up order control is mainly achieved by reducing the costs associated with cars' dwell time at the station $C_{wh}(X^{(t)})$. Despite the fact that cars' dwell time at the station yards affects the needful track quantity, the presented TBOC model in any way does not take into account the possible reduction in needful infrastructure as a result of effective trains' breaking-up order control. This can be explained by the following considerations. First, the reduction in unproductive dwell time of trains with accomplish car groups at the receiving yard does not lead to an overall reduction in trains' dwell time at this yard – a common dwell time, usually remains the same, with only its redistribution occurring between the trains with accomplish car groups and other trains. Second, reducing cars' dwell time in classification yard also cannot lead to a reduction in the necessary quantity of tracks in this yard. This is primarily due to the existing method of determining the necessary quantity of sorting tracks – based on the quantity of trains' formation destinations.

Let us assume that $\{\theta_i\} = \{\theta_1, \theta_2, ..., \theta_f\}$ – set of possible states of the system "Station – Adjacent approaches", that is defined by possible moments of trains' arrival to the station – $\theta_i = \{T_1, T_2, ..., T_k\}$. A set $\{\theta_i\}$ is based on statistical forecasting error on trains. Probability $P(\theta_i)$ of each state is known.

Given the possibility of the actual trains' arrival deviation from the forecast, we obtain the stochastic programming task [16]. Under these conditions, solving the problem of choosing the breaking-up order involves the choice of order, which provides the minimum expectation of total operating costs related with the processes of trains' formation. This expectation of operating costs is determined by considering all possible states, in which may be the station in case of the actual trains' arrival moments' deviation from forecasted ones:

$$C'(X^{(t)}) = \sum_{i=1}^{f}(C(X^{(t)};\theta_i) \cdot P(\theta_i)) \to \min_{\forall X^{(t)} \in X}, \qquad (4)$$

where: $C(X^{(t)};\theta_i)$ – total operating cost of the breaking-up order $X^{(t)}$ under conditions θ_i.

The TBOC model takes into account the possible risks of irrational decisions resulting from the inaccurate forecasting of trains' arrival. Of course, the TBOC model does not take into account all of the risks. For example, train, departed from the station, stemming from improved breaking-up order, may be delayed on the next nearest station. However, the planning horizon of the TBOC model is limited to the moment of the train departure from the station. In fact, this approach is reasonable, given the fact that with an increase in the depth of planning its reliability inevitably decreases.

The model TBOC was investigated in terms of economic efficiency. The study was performed by simulation modeling using the model developed at the Department of stations and junctions of DNURT. For this purpose, the universal simulation model was adapted to the station layout and technology of odd system of Nizhnedneprovsk-Uzel marshalling yard (Ukraine).

In the paper, the impact of the accuracy of the trains' arrival forecast on the efficiency of trains' breaking-up order control was studied. Control efficiency is understood here as a relative reduction in operating costs of marshalling station, achieved by changing the trains' breaking-up order. Accuracy of the forecasting was determined using standard deviation of forecasting error and varied ranging from 5 minutes to 25 minutes in steps of 5 minutes.

The trains' arrival is predicted on the basis of performed railway traffic – that is, the forecast of train arrival can be updated after this train passes the next railway station. As the train approaches the end point of the route, the accuracy of the prediction, of course, will increase. In the presented TBOC model, the arrival forecast compiled after the train passage at the last technical station before arriving at Nizhnedneprovsk-Uzel marshalling yard was used. The duration of the trains' movement between these two stations is about 50 minutes. Thus, the information about the predicted moment of the train arrival appears approximately 50 minutes before the actual arrival of the train.

The main economic effect of trains' breaking-up order control is achieved by reducing the unproductive dwell time of trains with accomplish car groups at the receiving yard. Such downtime is largely dependent on the size of traffic volume and processing load of the breaking-up subsystem. Therefore, the studies on the effect of accuracy forecasting on TBOC efficiency were performed for different car processing volumes. At the same time it takes into account the condition of compliance with a reasonable processing load level (in the range 75-85%) of the main perpetrators (car maintenance crews and shunting locomotives), limiting the capacity of the marshalling yard.

Besides, studies were performed at different depths of planning (i.e. with different number of trains) to be included in the count of breaking-up order variants. Simulation has showed that it is enough to fulfill planning of 4-5 trains. Further increasing the depth of planning does not improve the performance of the station. Test results for the depth of planning on 4 trains are shown in Fig. 1.

4. CONCLUSIONS

The results of simulation modeling allow formulation of the following conclusions:

- the increase in standard deviation of prediction error and the decrease in car processing volume significantly reduce the effectiveness of trains' breaking-up order control;
- with the amount of car processing volume of 3,000 car/day and standard deviation of forecasting error to 5 minutes, operating costs, depending on the trains' breaking-up order are reduced by up to 6.7%;
- with the amount of car processing volume of 2,500 car/day and standard deviation of forecasting error for about 25 minutes, the appropriateness of trains' breaking-up order control almost disappears;

– increasing the economic efficiency of TBOC by increasing the size of the car processing volume with is explained due to an increase in unproductive dwell time of trains in the receiving yard.

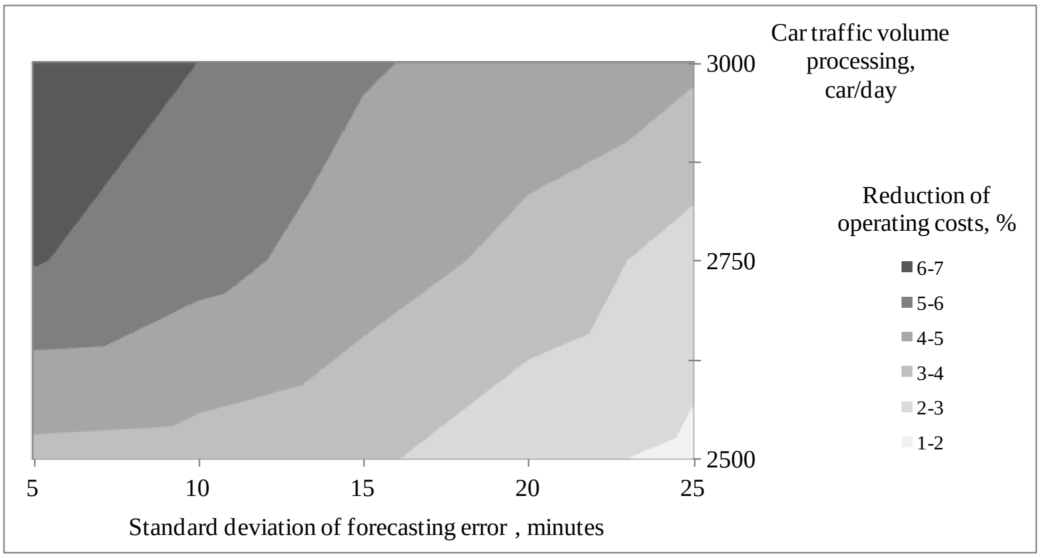

Fig. 1. Dependency of breaking-up order control efficiency from forecasting error

These results reflect the possible positive effects of trains' breaking-up order control on a Nizhnedneprovsk-Uzel marshalling yard. Features of effective trains' breaking-up order control depends also on a number of specific characteristics, which are individual for each station (for example, the quantity of approaches to the receiving yard and the quantity of tracks in the receiving and classification yards). Therefore, the question of generalization of the results to other marshalling yards requires additional research. In addition, the obtained results are adequate only if the functioning of the freight production system is similar to freight production system of Ukrainian railways. This system is characterized by the presence of strict requirements for weight and length of trains and the absence of strict scheduled train operations.

The feasibility of implementing technologies of trains' breaking-up order control for marshalling stations is largely determined by the accuracy of traffic forecasting at nearby stations. Besides, a reliable basis for the implementation of these technologies is the large size of the car processing and high load of marshalling station breaking-up subsystem.

For feasibility of practical use of trains' breaking-up order models, it is necessary to ensure two conditions:

– imposition of this function on automated control systems;
– providing an automated system with sufficiently reliable and accurate prediction of trains' arrival.

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