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scheduled train operation; time reserve; schedule; train schedule; train delay

Dmitriy KOZACHENKO*, Roman VERNIGORA, Vladimir BALANOV, Nikolay BEREZOVY, Lidiia YELNIKOVA, Yulia GERMANYUK
Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan
Lazaryana str., 2, Dnipropetrovsk, 49010, Ukraine
**Corresponding author*. E-mail: dmkozachenko@rambler.ru

EVALUATION OF THE TRANSITION TO THE ORGANIZATION OF FREIGHT TRAINS TRAFFIC BY THE SCHEDULE

Summary. The paper considers the issues of bulk conveyance organization between industrial enterprises on schedule. Currently the movement of the main part of freight trains is performed on preparedness and occupation processes of separate schedule train paths by some terminals are not fixed. And, due to the lack of statistical material on the punctuality of the schedule for the movement of freight trains, research of the passenger trains movement with subsequent dissemination of results on freight movement were carried out by the authors. The values of the additional time reserves that should be included in the schedule of trains, and the schedule for the turnover of freight trains to provide conditional interaction of railroads and industrial enterprises in Ukraine were proposed. The obtained results can be used for the technical-and-economic calculations of transition effectiveness of industrial enterprises for maintenance on schedule as well as in the development of schedule on the initial stages of testing technology.

ОЦЕНКА ЭФФЕКТИВНОСТИ ПЕРЕХОДА НА ОРГАНИЗАЦИЮ ДВИЖЕНИЯ ГРУЗОВЫХ ПОЕЗДОВ ПО РАСПИСАНИЮ

Аннотация. В работе рассмотрены вопросы организации перевозки массовых грузов между промышленными предприятиями по расписанию. Для того, чтобы обеспечить поступление поездов на станции назначения к заданному моменту времени графики оборота составов должны иметь резервы времени, достаточные для парирования воздействия дестабилизирующих факторов. Для исследования качества выполнения графика движения отдельными поездами использованы методы математической статистики. В настоящее время движение основной части грузовых поездов осуществляется по готовности и процессы занятия отдельных ниток графика определенными составами не фиксируются. Поэтому, ввиду отсутствия статистического материала по пунктуальности выполнения графика движения грузовыми поездами, выполнены исследования движения пассажирских поездов с последующим распространением результатов на грузовое движение. Предложены значения дополнительных резервов времени, которые должны закладываться в график движения поездов и график оборота грузовых составов, для обеспечения устойчивого взаимодействия железных дорог и промышленных предприятий Украины. Полученные результаты могут быть использованы для технико-экономических расчетов эффективности перехода промышленных предприятий на обслуживание их по расписанию, а также при разработке графиков движения на начальных этапах опробования технологии.

1. INTRODUCTION

The strategic direction of Ukraine's development is adapting its legal framework to the legislation of European Union. At the first stage of the adaption of the railway transport is one of the priorities. In accordance with the Directives of European Parliament and Council the railway transportations market should be open to the independent carriers. Under such organization of the market the infrastructure operator provides to the carrier services connected with the movement of its train on the railway road at a charge. The implementation of this model suggests the movement organization of independent carriers trains using the schedule agreed between them and the infrastructure operator.

In terms of freight transportations volume by railroads Ukraine ranks second in Europe after the Russian Federation. Each year the Ukrainian railway transport carries more than 380 mln. t. of cargo. Currently, Ukrainian railways are both the infrastructure operator and the carrier at the same time. As a rule the freight train departure is carried out when ready with the availability of car composition, locomotive and locomotive crew on the earliest free train path. The disadvantage of the traditional Ukrainian technology of freight railway transportations is significant unevenness of carriage duration. During operation of the common car fleets and locomotives and the centralized control such technology provides a sufficiently low cost of transportations and is acceptable to the shippers. However, the critical wear of railway rolling stock exceeding 80% and the lack of funds for its renovation has led to the appearing of independent car operators, and eventually it will lead to the appearing of the mainline locomotive operators. Considerable unevenness of transportations, which is characteristic of the technology for the train departure when ready, makes it necessary to create the rolling stock reserves for each of the operators. This leads to increase in transportations cost and decline in their competitiveness. The problem can be solved by means of the technology development for freight transportations according to the schedule based on the firm-time slots.

2. LITERATURE REVIEW AND DEFINING THE PROBLEM

What are the reasons for the freight trains deviation from the schedule? Firstly, during development of the train schedule the design values of train locomotives and rakes are taken as the basic data. The deviation of the actual parameters of locomotives and rakes from the design ones and the individual characteristics of drivers lead to a change in movement time of trains. Secondly, in the cargo movement the stimulation of drivers for fuel and power economy is practiced. In this regard, in the presence of the capacity reserves the optimization of train movement mode in terms of energy consumption is carried out. This leads to an increase of their travel time on 5-30% [1]. Finally, the increase in travel time of freight trains occurs because of the variety of failures of technical, technological and other nature [2].

Thus, the transportation process is exposed to a significant number of random factors. In this regard, the provision of train movement according to the schedule requires the use of special methods at the stage of development of the train movement schedules, locomotives and rakes turnover.

There is no legal framework of freight train movement organization according to the schedule in Ukraine. At the same time, this technology is widely used on the railroads in North America and the European Union.

The methods to ensure the punctuality of railway transportations are presented in [3]. At the same time, the train arrival at the station of destination in accordance with the schedule is provided by the application in the schedule of various time reserves:

- determination of the permissible delay time;
- artificial increase of travel time;
- creating an additional time interval with the preceding train.

International Union of Railways in [4] recommends determining the movement time additions as follows: 1 minute per 100 km plus 3% of the travel time or 3 minutes per 100 km, or 4 minutes of travel time. In some countries other regulations are used. Thus, in the Netherlands [5] during the schedule development the maximum permissible speed of freight trains is taken as 5 km/h lesser

than the possible one, and the calculated travel time of trains is increased by 5%. The fact that the schedule is calculated for the maximum weight of the train is taken into account as an additional time reserve. Under the circumstances, there is a possibility to reduce the acceleration and braking periods for the trains with lesser weight. In Switzerland the travel time addition is set in the amount of 11%. In the UK the values of the travel time additions are not constant and are established on the basis of the performance analysis for the previous period.

Also, in the countries where it is practiced the departure of freight trains according to the schedule there are established the norms of permissible time delay. For example, the maximum permissible delay of the scheduled freight train in Denmark is 10 minutes, in Germany – 30 min [6].

In Russian Federation is effective "The guide for organization of train operation when the freight trains departing on the firm-time slots" [3]. In accordance with this document the provision of schedule fulfillment is achieved by additional reserves of travel time. Thus, to provide the passage of freight trains with differential weight (including the heavy ones) on the same paths with the trains of universal weight and for the stable fulfillment of the train movement schedule in accordance with [3] it is necessary to provide for the following time reserves:

- to the calculated between station travel time of the trains in the amount of 3-5%;
- on the last between station block of the locomotive crews operation for all freight trains in the amount of 2...4 minutes;
- to avoid the delay transmission from one train to the others (in the form of increased calculated train to train intervals or schedule periods on the limiting between station blocks up to 2 minutes).

However, it should be noted that the movement schedule fulfillment by freight trains in the Russian Federation, as well as in the other CIS countries can be assessed only within certain sections due to lack of standards for the accurate performance of their travel time from the departure station to the destination station.

Currently, on the railway network of Ukraine it was organized a large number of circular cargo transportations, when own cars move from the consignor to the consignee and back for the next load. Examples of such shipments are the delivery of iron ore raw material from Poltava mining and processing complex to cargo terminals of «Transinvestservice» (TIS) in Yuzhny seaport [7], delivery of billets from the metallurgical plant "Interpipe Steel" to the tube rolling plant "Niko Tube" [8], the transportation of transit cargoes from the border stations to the sea ports [9], etc. Prospects of development of the Silk Road through the territory of Ukraine [10] may also help to increase of circular cargo transportations. At the same time, the coordination of technological processes of enterprises and the railway transportation using the organization of freight train movement according to the schedule and the cargo delivery "just in time" is considered as the method of efficiency increase of car use, reduction of raw material stocks, reduction of handling capacities reserves and, as a result, the reduction of the total logistics costs. However, the transition to transportation organizing according to the schedule is connected with additional costs from the carrier, shipper and consignee, which requires the corresponding economic feasibility. Considering significant difference between the conditions of the organization of transportations in Ukraine and the European Union countries, technical support and technical condition of the railway network and rolling stock one cannot directly apply the methods and norms existing on the railways of other countries. Therefore, the aim of the study is influence assessment of the transition to the organization of freight trains according to the schedule on the operation of the transportation process participants.

3. METHODOLOGY

In order to ensure the incoming of trains to the destination stations at a given moment of time the schedules of train turnover should have sufficient time reserves to compensate the influence of destabilizing factors. Reserves may be of two types. Part of the reserve should be provided for in the schedule, and part of it - at the destination station from the moment of train arrival in accordance with the movement schedule till the moment of start of technological operations with its cars and locomotives. At the same time insufficient reserves may cause failures in the technological processes of

enterprises, conflicts during the occupation of between station blocks and the substantial secondary delays. Excess reserves cause performance degradation in the use of locomotives, locomotive crews, cars, station tracks and the reduction of between station blocks capacity.

Processes occurring on the railway transport are of stochastic nature. In this context, to study the quality indicators of fulfillment of the train movement schedule the methods of mathematic statistics were used [11]. The starting material for the statistical processing was obtained on the basis of observation of the actual functioning processes of the mainline railway transport and the approach lines of industrial enterprises. The influence of arrivals and departures of freight trains on the railway transport operation of the industrial enterprises was estimated on the basis of the simulation of their operation process.

Currently, the movement of the main part of freight trains is carried out when they are ready and the processes of occupying the separate train paths by certain trains are not fixed. Adherence to the movement schedule is not the aim of operational control of freight transportations. Therefore, the schedule analysis of fulfilled movement of freight trains does not allow obtaining the material to study. At the same time, the passenger trains departure and their passage of stations is carried out strictly according to schedule. The features of passenger transportations, as compared to the freight ones are tight fixing of the locomotives to trains, operation of the locomotive crews according to the registered schedules, control of the train movement by the dispatching apparatus with the organization of activities for priority passage of the passenger trains and making up for delay. The passenger services are fixing the cases of passenger trains deviation from the schedule, classifying and analyzing them. It is necessary to notice that there are distinctions in conditions of performance for the passenger and cargo transportation according to timetable, which are first of all in different reliability of rolling stock and service technology of trains on the stations. However, at this stage of the investigation, this distinction was without consideration. Given the commonality of processes the passenger train delays were studied to apply the conclusions to the freight traffic.

The initial data concerning delays were obtained on the basis of the processing of analysis of the passenger trains movement schedule of passenger service of the Prydniprovsk railway for 2012-2013. While analyzing, the train number, place, time and duration, as well as the reason for delay are fixed.

During the studied period of time the 86.446 of passenger trains traveled through the Prydniprovsk railway. 941 of these trains deviated from the movement schedule. The main causes of passenger trains delays are the failures of track laying, power supply, signaling, train locomotives and cars, their partial failures such as speed limits, maintenance and repair of infrastructure, human errors, unauthorized interference in the work of railway transport, natural and manmade emergency situations, as well as the secondary delays due to the deviation from the movement schedule of other trains.

The greatest number of delays is associated with the locomotive facilities, track and power supply. 54% of cases are accounted for by these delays. The longest delays are attributed to the category of "Other" and are associated with natural disasters, accidents at crossings, unauthorized interference in the work of railway transport, etc. The histogram and the function of density distribution of the random value of the train delay are shown in the Fig. 1.

Generally, the study is concluded by the fact that the set of measures used in passenger traffic ensures the schedule fulfillment with a probability of 0.99. With a probability of 0.01 the train travels with delay. Statistical analysis showed that the random value of delay has the distribution law, which is close to the exponential one. At the same time the mathematic expectation of delay is $\bar{t}_d$ =43.9 min.

4. INVESTIGATION RESULTS

The studies allow us to establish the necessary reserves of time to ensure the sustainable transportations. Thus, during the construction of train movement schedule engineers-graphic designers added the reserve to the travel time in the amount of 4 minutes per 100 km (which corresponds to an increase in travel time by 3-5%). This allows one to ensure the fulfillment of passenger trains schedule

in the absence of failures of technical equipment and human errors. The delay of train arrival at the destination takes place at a frequency close to 1 per 100 trains. It should be noted that the schedule of passenger train movement is developed for their maximum weight. In this regard, passenger trains, which have a lower weight, have some additional time reserve owing to acceleration and deceleration. During organization of freight trains movement between enterprises, their mass will not significantly change. This limits the ability to make up for delay. Therefore, it is advisable to increase the time reserves for freight trains up to 5-7% of the travel time.

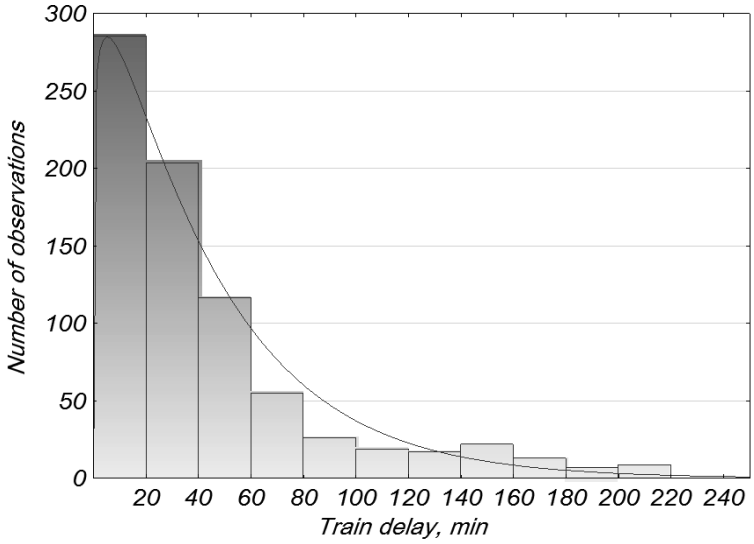

Fig. 1. The histogram and the function of density distribution of the random value of the train delay
Рис. 1. Гистограмма и функция плотности распределения случайной величины задержки поезда

If it is necessary to improve the quality of fulfillment of train movement schedule and to compensate most of the failures at the destinations the additional time reserves can be created. The reserve capacity can be found using the formula

$$t_r = -\bar{t}_d \ln \frac{n_{pd}}{N p_d^*} \tag{1}$$

where: n_{pd} – is permissible number of trains arriving to the start of technological operations at the plant with delay; N – is the total number of trains running on the route during the year; p_d^* – is the frequency of train delay.

The value of the selected time reserve t_r makes it possible to determine the expected number of trains arriving at the enterprise with delay

$$n_d = N p_d^* e^{-t_r/\bar{t}_d} \tag{2}$$

If one sets similar to the railways of Germany [5] the permissible time delay of 30 minutes on the railways of Ukraine, then with the traffic amount between enterprises in one train per day, one can expect no more than two delays per year (1.85 of the train). Reduction of the number of delayed trains up to one per year requires an increase in the time reserve up to 60 minutes. It is not rational because of the emergence of additional down time of the locomotives 30 min.

Servicing of industrial enterprises according to the schedule also leads to a change in their working conditions. These processes are studied on the basis of analysis of the car turnover during the transportation of iron ore raw material between the approach lines of the Poltava mining and processing complex and the transport hub TIS. These approach lines can be considered as multiphase

queue systems (QS). Arriving and departing cars form the incoming and outgoing traffic volumes for them. Servicing consist in performing of freight and technical operations with cars. At present, the above mentioned QS can be described as QS with random intensity of the incoming traffic volume, random duration of servicing and the random intensity of the outgoing traffic volume. If during organization of train movement according to schedule the organization of approach line operation is not changing, then the QS with constant intensity of the incoming traffic volume but with random time of servicing takes place. At the same time, the departure of trains according to the schedule is achieved using the additional time reserve in waiting for the train departure. To estimate the additional downtime of cars at the approach lines during the organization of train movement according to schedule a simulation model was used. In this model, the process of cars circulation between stations of loading and unloading was divided into stages: loading, storage, delivering of loaded car, unloading, storage, delivering of empty car. To simulate the process the following objects were described: car during cargo operations, classification track for train storage and train. Technology of objects servicing was formalized in the form of finite automata. As example, the finite state automata that simulates the work of classification track is presented in the Fig. 2.

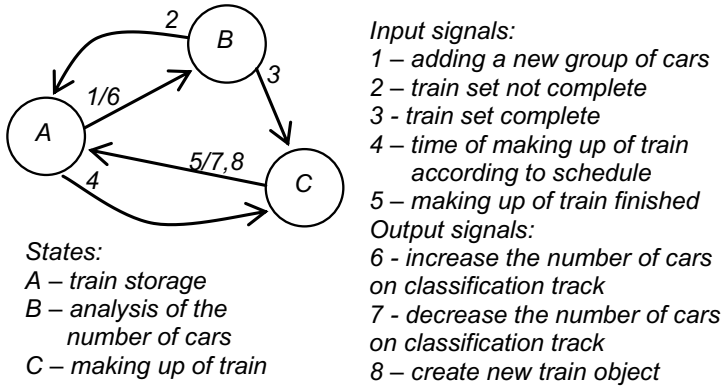

Fig. 2. Finite state automata that simulates the work of classification track
Рис. 2. Конечный автомат, моделирующий работу сортировочного пути

The results of simulation are the values of cars downtime in various stages of transportation process. Dependence example of additional car demurrage at the approach line of TIS on the average daily number of trains is shown in the Fig. 3.

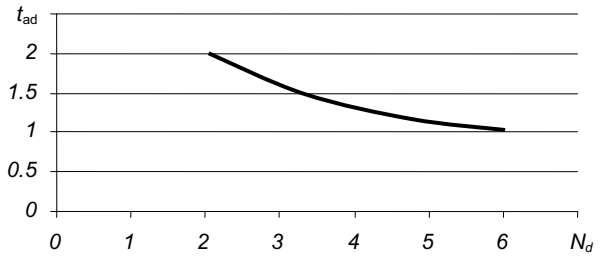

Fig. 3. Dependence of the average additional car demurrage t_{ad} arising at the approach line of TIS during organization of transportations according to the schedule on the average daily number of trains N_d
Рис. 3. Зависимость среднего дополнительного простоя вагонов t_{ad}, возникающего на подъездном пути ТИС при организации перевозок по расписанию, от среднесуточного числа поездов N_d

In general, when organizing the freight train movement according to the schedule during transportation of 8 mln. t. of iron ore raw material from the Poltava mining and processing complex TIS the average speed increase by 85% and reduction of the cars turnover at 21 hours (20%) is achieved.

This provides economic effect of reducing the costs for railway cars no less than 2.5 mln. USD per year. On the other hand, the simulation results showed that the implementation of schedule for freight train movement provides the reduction of coefficient of the daily unevenness of transportations from 1.46 to 1, which directly affects the size of the locomotive fleet and the staff of locomotive crews of Ukrzaliznytsia, as well as the required power of the handling facilities of the Poltava mining and processing complex and TIS.

On the basis of the conducted research the methods for development of train turnover schedules ensuring the transportations of goods according to schedule were improved. The obtained results can be used for technical and operational calculations of transition efficiency of industrial enterprises to servicing according to the schedule, as well as for development of movement schedules at the early stages of technology testing.

5. CONCLUSION

In order to ensure the arrival of trains running according to the schedule at the destination stations "just in time" the schedule should include the time reserves to reduce the influence of random factors on transportation process. For the railways of Ukraine it is advisable to install the time addition to the travel time in the amount of 5-7 minutes, to set the permissible delay time at the destination station 30 minutes.

Organization of cargo transportations according to the schedule if it is needed to form the full length trains necessitates the additional downtimes of cars at the approach lines. With mass transportations of goods the value of additional downtime is 1-2 hours per car.

The obtained results may be used for technical and economic calculations of the transition efficiency of industrial enterprises to their servicing according to schedule, as well as for development of movement schedule at the initial stages of testing the technology. After the accumulation of statistical data according to the results of freight transportations in accordance with the schedule the offered values of time reserves may be specified.

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