ORIGINAL ARTICLE
DOI: https://doi.org/10.30932/1992-3252-2021-19-4-12

World of Transport and Transportation, 2021, Vol. 19, Iss. 4 (95), pp. 266–272

Improving Information Interaction between the Metallurgical Plant and Rail Operators

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ABSTRACT

The current situation of development of the world economy presupposes intense competition in both external and internal markets. Under these conditions, it becomes more and more obvious that the growth of profits and, accordingly, further development of companies will be carried out not so much through expansion, but through improved service for customers, an increase in the range of goods and services offered, a better product quality and a decrease in production costs.

The main role in optimisation of technological processes is currently played by digital transformation of production. The introduction of advanced information technologies is of great importance for all global companies, since the enhanced development of information systems results in improvement of business processes, better safety, and environmental friendliness.

International studies show that the use of modern information technologies in transport industry is necessary to improve traffic safety, reduce environmental impact, increase the efficiency of the transportation process.

The Russian mining and metallurgical sector, along with the oil and gas industry, makes a significant contribution to development of the country. Complex production technology, a large volume of traffic, hazardous and dangerous working conditions for personnel necessitate development of a digital environment to increase labour productivity and the volume of products.

The objective of the research is to study the possibility of using information control and forecasting systems for solving technical, technological, and organisational problems of industrial railways of metallurgical plants.

Based on comparative analysis, general scientific and mathematical research methods and the study of the role of information systems in digital transformation of production process, the authors suggest a methodology for creating a stochastic model for predicting the arrival of unit trains at an enterprise, and consider development trends in digital transformation of industrial transport.

Keywords: *railway transport, stochastic modelling, metallurgical enterprise, information systems.*

For citation: *Popov, A. T., Suslova, O. A., Kobernitsky, A. A., Khlemev, A. S. Improving Information Interaction between the Metallurgical Plant and Rail Operators. World of Transport and Transportation, 2021, Vol. 19, Iss. 4 (95), pp. 266–272. DOI: https://doi.org/10.30932/1992-3252-2021-19-4-12.*

The text of the article originally written in Russian is published in the first part of the issue.
Текст статьи на русском языке публикуется в первой части данного выпуска.

INTRODUCTION

The results of international studies advocating positive role of modern information technology in the transport sector increasing safety, reducing environmental impact, and raising efficiency of transportation [1, p.12; 2, p. 36; 3, p. 692] can be fully applied to analyse the operations of the industrial transport, namely, to industrial railways.

Today, almost every industrial enterprise has its own developed logistics system, the efficiency of which influences the productivity of its productive capacity, vehicle turnover and company costs.

The cost of production of metallurgical plants depends on a correctly built strategy for delivery of raw materials from mining sites to the workshops of the main production site, and then to the consumer. Reducing the cost of transportation and storage of goods, increasing monthly and annual turnover of products have a positive effect on the efficiency of the production process.

Therefore, the systemic development, optimisation and improvement of all logistics supply and sales chains are important since future development of an industrial enterprise depends on them.

The main role and task of logistics is procurement, supply, marketing, transportation, and storage of commodities and material assets.

The research paper offers the results of a study conducted with an *objective* to analyse and forecast of promising forms of interaction of an industrial enterprise of a full production cycle (metallurgical plant) with operators that own rail rolling stock [4, p. 299]. In general terms, this can be represented as interaction of mainline railway transport and non-public transport. At different stages of the study, a forecasting method was based on statistical mathematical stochastic model with elements of the probability theory.

Transport logistics is a complex planning process based on an analysis of demand for finished products in accordance with the needs of consumers. Knowing final parameters in terms of production volumes, specialists choose the required type of rolling stock, its required quantity, plan the volumes and routes of transportation, considering conditions for minimising transport costs, and prepare necessary transport documents. The work results in satisfaction of the demand for finished products and provision of production workshops with raw materials.

Logistics can be divided into two types:

1) internal logistics, which provides transport services for workshops within the production site (for example, transportation of hot pig iron from a blast furnace workshop to a converter workshop);

2) external logistics, the purpose of which is interaction between various enterprises, namely, suppliers and consumers, in the field of transportation of raw materials, finished products, equipment and other goods by means of mainline transport.

Logistics in the activities of an enterprise is the main connecting link between all stages of production, and at this stage of technology development followed by sophistication of supply chains, it is impossible to effectively manage production and commercial activities of the enterprise without the use of powerful information decision support systems.

RESULTS

Predicting the Arrival of Wagon Flows

When building a forecasting model for arrival of wagons at the enterprise, it is necessary to determine the boundaries of the forecasting period, or the planning horizon. It is exactly this model that will be the basis for functioning of the information system for monitoring and forecasting work of the railway of a metallurgical plant.

It should be borne in mind here that the forecasting horizon should be optimal from both technical and economic points of view. With an increase in planning periods, uncertainty also grows due to the fact that the number of factors affecting movement of rolling stock through the network increases, therefore, the forecast accuracy decreases. The planning horizon is conventionally divided by the authors into three tiers of forecasting (Pic. 1):

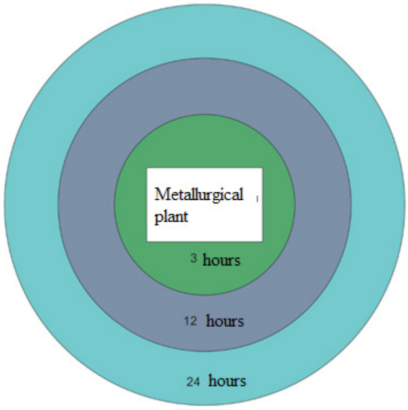
1) operational: a three-hour period;

2) shift: twelve hours;

3) daily: twenty-four hours.

After determining the planning horizon, it is required to develop a model for predicting arrival of wagons at the metallurgical plant. This will improve the technological interaction of industrial and mainline railway transport at the interchange stations by improving the quality of planning of train work for exchange of trains, which will lead to a reduction in turnover of wagons, an increase in performance rates of locomotives that move trains to and from interchange points and a decrease in occupancy of elements of the track infrastructure.

Currently, there are several forecasting methods [5, p. 120; 6, p. 74; 7, p. 320; 8, p. 129]:



Pic. 1. Tiers of wagon traffic forecasting (compiled by the authors).

1) Intuitive methods that are based on findings of experts in the field of study;

2) Mathematical methods, which are based on the mathematical apparatus and are subdivided into:

- domain models;
- time series models:
  – statistical models;
  – structural models.

In this study, to predict arrival of unit trains, the authors propose to apply a statistical mathematical stochastic model using elements of the theory of probability. For this, the travel time through the network from the departure station to the destination station of each train will be taken as a probabilistic experiment for the following reasons: for the metallurgical industry, trains with raw materials are sent regularly and daily, the trains are of the same type and the route is similar. Besides, arrival of the train at the facility at the *i*-th moment of time is a random event since an infinite number of factors act on the unit train during the journey, which cannot be fully considered. For example, they may comprise a breakdown of a locomotive, hitting a technological traffic interval, detection of a wagon defect with subsequent uncoupling, the effect of human factor in the actions of locomotive crews, train dispatchers, station attendants, etc. Thus, the travel time of the train is a random variable.

The predicted time of arrival of the train at the station is generally defined as:

$$t = t_{i\ ship} + t_{i\ travel}(P), \quad (1)$$

where t_{iship} – time of shipment, h (days);

$t_{i\ travel}(P)$ – a function of travel time to the destination station, depending on the probability P, h (days).

This shows that the value of the predicted arrival time is probabilistic, and the function itself is probabilistic.

As an example, the authors consider a sample of 100 values of the travel time of trains with dry-quenched blast-furnace coke in the summer period from Zarinskaya station to Novolipetsk station in days. All calculations of numerical characteristics of a random variable were made by the team of authors using *mathematical methods* in the Statsoft Statistica program. The resulting histogram of the distribution of values in comparison with the Gaussian distribution curve is shown in Pic. 2.

Application of the *method of comparative analysis* shows a significant deviation of the histogram to the left from the normal distribution curve, an elongation of the right «tail» and a pronounced peak. Checking the specified distribution for normality is carried out using the Kolmogorov–Smirnov and Shapiro–Wilk tests.

Research by the Kolmogorov–Smirnov method [9, p. 60]:

$$D_n = \sup_x |F_n(x) - F(x)|, \quad (2)$$

where $\sup_x$ – exact upper bound of the set;

$F_n(x)$ – distribution function of the studied population;

F(x) – normal distribution function.

The allowed value of the significance level is more than 0,05. Otherwise, the hypothesis of normality is rejected.

Checking according to the modified Shapiro–Wilk criterion is carried out according to the formula [10, p. 605]:

$$W = \frac{[\sum_{i=1}^{n} a_{n-i-1}(x_{n-i-1} - x_i)]^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}, \quad (3)$$

where *i* – ordinal number of the element in the studied row;

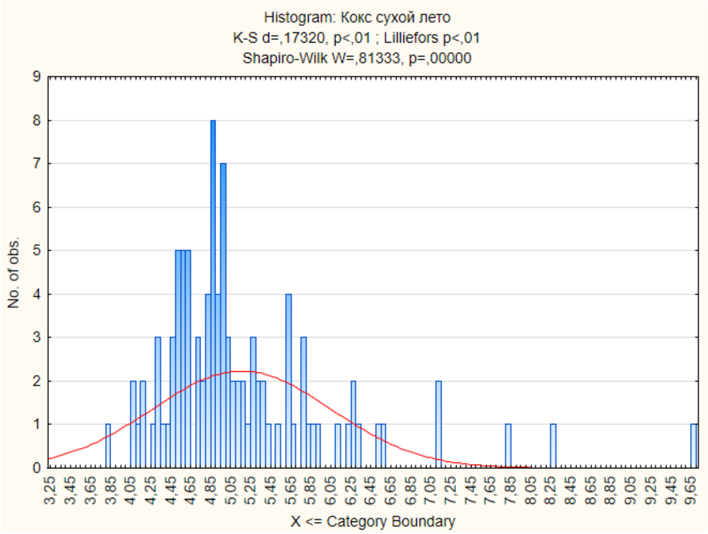
n – volume of the population;

– arithmetic mean value;

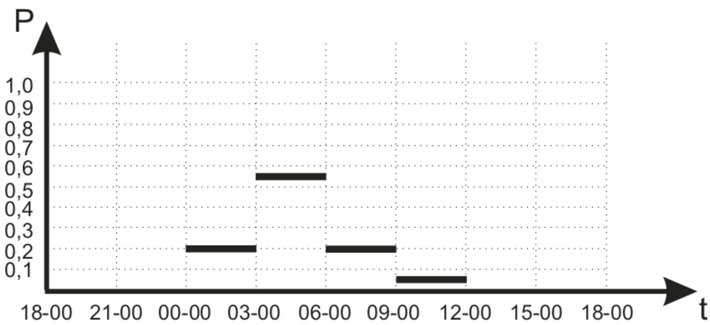
a_{n-i-1} – tabular coefficient.

Checking according to the specified criteria using the Statistica software package shows a discrepancy between the studied distribution and the normal one. According to the results of the study in the Statistica program, the authors determined the numerical characteristics, which are given in Table 1, and built a graph of the predicted arrival time for a daily period with three-hour intervals in general form for the dry quenching coke train (Pic. 3).

The constructed schedule of the planned arrival is automatically transmitted to the internal information system [11, p. 231].



Pic. 2. Histogram of distribution of travel time of the trains (compiled by the authors).



Pic. 3. The graph of the probability of arrival of a train within a three-hour interval (compiled by the authors).

Automated System for Monitoring the Position of Rolling Stock on Railway Tracks of an Industrial Enterprise

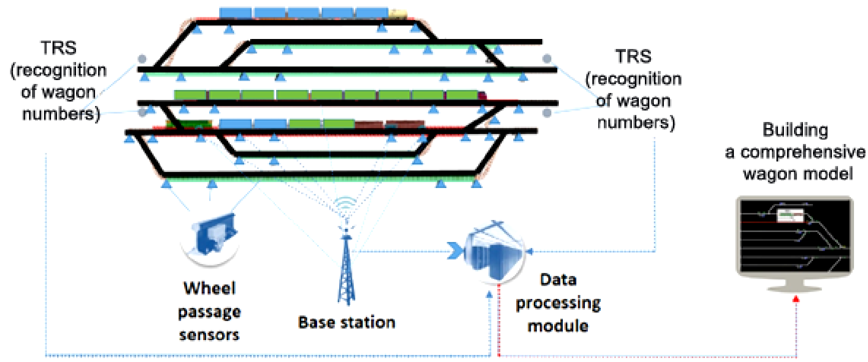
An in-depth study of the issue of logistic interaction between an industrial enterprise and rail operating companies shows that this process is trilateral: production workshops, industrial transport system and main transportation lines are inextricably linked [12, p. 636].

The development of a single information field will allow all participants in the logistics process to monitor the relevant performance indicators of the transport system, to cover by planning and permanent control the entire logistics chain from the moment of inception of the traffic flow to its consumption, and to build a strategy for further development [13, p. 265].

After adoption of a single automated system for monitoring the positioning of rolling stock at the enterprise, all processes through which the wagon passes at the industrial site will be visualised. The concept of the system's operation for an industrial railway station of a metallurgical enterprise proposed by the authors is shown in Pic. 4.

This system controls movement of wagons on the production site and the time of technical and commercial processing of trains, increases speed of acceptance and dispatch of goods and of related document flow operations, and minimises the influence of the human factor. In the future, it is planned to introduce elements of artificial intelligence, the algorithm of which will allow calculating the most optimal shunting routes to reduce transport costs and risks.

Recognition of the inventory wagon numbers (with the help of TRS, technical registration system) is made with a probability of at least 95 % (for clean, well-readable numbers that meet the numbering requirements of the freight fleet of 1520 mm gauge railways) under any weather conditions and varying degrees of illumination.



Pic. 4. The concept of the system for monitoring movement of wagons and locomotives in real time (compiled by the authors).

A screenshot of the software program running at the railway station of the metallurgical enterprise is shown in Pic. 5.

Thus, the information system makes it possible to fully automate the process of documentary registration of passage of trains through the controlled area, providing inspection functions in technical and commercial terms. The data obtained can be used both for recording and accounting purposes and as an evidence base in the event of disputable situations with counterparties [14, p. 55].

With the help of the system for monitoring the position of rolling stock, each participant in the transportation process can monitor in real time specific performance indicators.

Using a comparative analysis, it is possible to highlight the advantages of the automated rolling stock positioning monitoring system:

1)For production workshops:

• control of movement of wagons with raw materials both on the external and internal sites;

• control over supply of empty rolling stock for loading finished products;

• data correction and input of additional information for other participants;

Table 1

Numerical characteristics of a random variable (compiled by the authors)

Name of the characteristics	Designation	Value
1	2	3
Mathematical expectation	M	5,159
Median	Med	4,942
Standard deviation	σ	0,798
Asymmetry coefficient	β_1	2,237
Coefficient of kurtosis	β_2	7,333
Confidence interval, 95 %	–	(3,378; 6,940)

• optimisation of interaction between the main production facilities and the industrial transport system that serves it [15, p. 66].

2)For non-public transport:

• control over movement of loaded and empty rolling stock both on the backbone network and at the production site;

• coordination of interaction between production departments and mainline transport, considering parameters entered by other participants in the transportation process;

• reduction of transport costs, subject to implementation of best routing;

• control of movement of locomotives, which will increase the efficiency of using traction rolling stock on non-public tracks [16, p. 53].

3)For companies of operators, owners of wagons of the external fleet:

• visualisation of the entire logistics process, which allows predicting time of delivery of rolling stock to the network.

• planning of dispatched wagon flows.

The Economic Component of the Project

The economic component of the project for an industrial enterprise, provided that an automated system for predicting arrival and monitoring the position of rolling stock on non-public railway tracks at the production site is put into operation, will be assessed in the form of an annual economic effect and a payback period:

$$T = C/(E - M), \quad (4)$$

where T – payback period of the project, years;

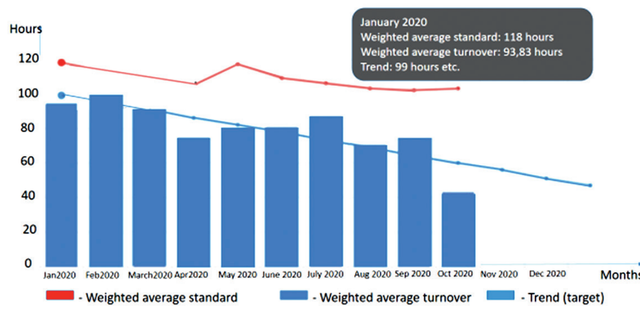
C – capital expenditures for implementation of the project, rubles;

M – additional annual costs of maintaining the system, rubles;

E – economic effect of the project, rubles:

$$E = (\tau_2 - \tau_1) \cdot W \cdot R, \quad (5)$$

Pic. 5. An example of the system's operation to control movement of rolling stock (compiled by the authors).



Pic. 6. Monthly weighted average turnover of wagons at the industrial site before and after introduction of the system (compiled by the authors).

where τ_2, τ_1 – average time spent by wagons on the industrial site before and after introduction of the system, h;

W – annual number of wagons arriving at the enterprise, wagons;

R – rate of attraction of rolling stock per unit of time, rubles/wagon-hour.

The team of authors determined the monthly weighted average turnover of a wagon at the site according to data for 2020 (Pic. 6).

All the calculated economic data given in the article are indicated according to expert estimates.

Capital expenditures C for introduction of this project will amount to 31 million rubles.

Annual operating costs M after introduction of the system will amount to 1,9 million rubles/year.

The positive forecast for reduction of the indicator of the turnover time of wagons within the industrial site gives reason to believe that an economic effect will be achieved due to [17, p. 187]:

- optimisation of labour costs for control of incoming and outgoing wagons – 4,8 million rubles/year;
- monitoring compliance with the carrier's requirements – 2,4 million rubles/year;
- reducing the cost of document management regarding wagons – 2,5 million rubles/year.

Thus, the total economic effect following the adoption of the system should be about 9,7 million rubles per year. Consequently, the payback period of the project will be 4 years.

CONCLUSION

Improving the information interaction of all participants in the transportation process will bring an economic effect by improving quality of operational work, reducing labour costs, turnover of wagons both on the siding track of the enterprise and on the external network [18, p. 183].

The predictive mathematical apparatus will allow planning a uniform arrival of trains at the interchange stations, while the automated control system of rolling stock on the siding track will make an optimal plan for shunting operations with arriving rolling stock. Improving the algorithm of the system's operation, as well as its further training, for example, based on artificial neural networks, will provide an even greater technical and, therefore, economic effect.

High prices for metals in foreign and domestic markets, together with an increase in production volumes, cause an increase in the volume of transportation of ferrous metallurgy goods. If this trend continues, the economic effect will be higher than the predicted one.

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Article received 20.05.2021, approved 25.08.2021, accepted 10.09.2021.