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IMPROVING THE METHODS OF ESTIMATION OF THE UNIT TRAIN EFFECTIVENESS

Summary. The article presents the results of studies of freight transportation by unit trains. The article is aimed at developing the methods of the efficiency evaluation of unit train dispatch on the basis of full-scale experiments. Duration of the car turnover is a random variable when dispatching the single cars and group cars, as well as when dispatching them as a part of a unit train. The existing methodologies for evaluating the efficiency of unit trains' make-up are based on the use of calculation methodologies and their results can give significant errors. The work presents a methodology that makes it possible to evaluate the efficiency of unit train shipments based on the processing of results of experimental travels using the methods of mathematical statistics. This approach provides probabilistic estimates of the rolling stock use efficiency for different approaches to the organization of car traffic volumes, as well as establishes the effect for each of the participants in the transportation process.

СОВЕРШЕНСТВОВАНИЕ МЕТОДОВ ОЦЕНКИ ЭФФЕКТИВНОСТИ МАРШРУТИЗАЦИИ ЖЕЛЕЗНОДОРОЖНЫХ ПЕРЕВОЗОК

Аннотация. В статье представлены результаты исследований перевозок грузов по железной дороге отправительскими маршрутами. Целью статьи является разработка методов оценки эффективности маршрутизации перевозок на основании натурных экспериментов. Продолжительность оборота вагонов как при отправлении одиночных вагонов и групп вагонов, так и при отправлении их в составе отправительских маршрутов представляет собой случайную величину. Действующие методики оценки эффективности формирования отправительских маршрутов основываются на использовании расчетных методов и их результаты могут давать существенные погрешности. В работе представлена методика, позволяющая оценить эффективность маршрутизации перевозок на основании обработки результатов опытных поездок с помощью методов математической статистики. Такой подход позволяет получить вероятностные оценки эффективности использования подвижного состава при разных методах организации вагонопотоков, а также установить эффект для каждого из участников перевозочного процесса.

1. INTRODUCTION

Using unit train technology is an efficient method of transportation process organization, which provides acceleration of the freight car turnover, reduction in the number of yard operations at the train stations, and reduction of the cargo delivery time. Organization of unit train turnover affects the interests of shippers, consignees and carriers. At the same time use improvement of the railway infrastructure and traction rolling stock necessitates an increase in the cargo handling capacity and track capacity of shippers and consignees. Under these circumstances, improvement of the cost estimation methods of the unit train using is a rather urgent task.

2. LITERATURE REVIEW AND DEFINING THE PROBLEM

A unit train is a freight train composed of cars carrying a single type of commodity that is all bound for the same destination. By hauling only one kind of freight for one destination, a unit train does not need to switch cars at various intermediate junctions and so can make nonstop runs between two terminals. This reduces not only the shipping time but also the cost. The unit train was introduced by American and USSR railroad companies in the 1950s and was used primarily to haul raw materials [1, 2]. At first mainly coal and ore were transported by the unit trains. Over time, this technology has been used for the transportation of grain [3], oil and petroleum products [4, 5], and containers [6]. Transportation of goods in unit trains makes it possible to reduce the cost of promotion of the car traffic volumes, but this is achieved by increase of expenditures at the stages of making up and breaking up of the unit trains. Using the unit trains is efficient when transporting the cargoes for long distances [7]. At the same time during transportation for medium and short distances logistic costs at the unit train transportation can be greater than that of the collective car dispatch or when using the alternative modes of transport [8]. In particular, the railways of Korea, for which the transportation distance is 400-500 km, have faced such problems [9]. The same situation is typical for the Ukraine too, where the average transportation distance is 560 km. In connection with this estimation of the economic efficiency of unit trains, technology improvement is an urgent task.

Currently, the effectiveness of using unit trains at Ukrainian railways is estimated in accordance with the methodology presented in [10]. The calculations are carried out during the development of the trains making up plan. At the same time, in order to include a separate cargo correspondence in the unit train making up plan, it should satisfy the condition that the additional costs for the organization of unit train turnover, compared to the usual technology at the station for loading E_{sl} and unloading E_{su}, will not exceed the economy in transit E_{ec}^{tr}. This condition is represented by the expression

$$E_{sl} + E_{su} \le \Delta E_{ec}^{tr} . \quad (1)$$

The total economy in transit is determined by the formula

$$E_{ec}^{tr} = \left(\sum t_{ec} + t_{ec}^{sl} + t_{ec}^{su} \right) N e_{nH} + N e_{nH}^{av} \sum r , \quad (2)$$

where: $\sum t_{ec}$ – is the total economy of the reduced freight car-hours when running through the marshaling yards, division terminals and cargo stations without yard operations; t_{ec}^{sl}, t_{ec}^{su} – is the time economy at the division of loading and unloading of the intermediate stations, correspondingly; N – is a routable car traffic volume; e_{nH} – is an expenditure rate for one car-hour for the car, which is included in the unit train, taking into account the type of cargo; e_{nH}^{av} – is an average network expenditure rate for one car-hour; $\sum r$ – is a total equivalent of the yard operation and locomotive changing at all stations, which the unit train will run without processing

Additional costs for the loading and unloading stations are determined by the formulas

$$\Delta E_{sl} = \Delta t_l N e_{nH} , \quad (3)$$

$$\Delta E_{su} = \Delta t_u N e_{nH} , \quad (4)$$

where: Δt_l, Δt_u – are the additional idle hours at loading and unloading stations, as compared to the collective car dispatch correspondingly.

Additional idle hours at the loading stations with unit train dispatch, as compared to the collective car dispatch, are defined as

$$\Delta t_l = \left(t_r^i - t_{nr}^i\right) - t_{ec}^{cst}, \tag{5}$$

where: t_r^i, t_{nr}^i – are the average idle hours of the car at the approach line and the connecting station correspondingly, car-h; t_{ec}^{cst} – is the economy of the reduced car hours, which is formed at the connecting station during the passage of the unit train loaded at the approach line by elimination of the sorting of the incoming cars exchange and time expenditures for car delivery removal, car-h.

The methodology presented in [10] has some disadvantages:

- firstly, it is focused on the efficiency estimation of the unit train transportation in the circumstances where transportation at the network of railways is carried out in the cars belonging to the railways;
- secondly, it does not take into account interests of the railway clients.

Market reforms in the Ukrainian economy and economies of other CIS countries resulted in the fact that currently major customers of the railway mainly use for transportation their own rolling stock or the one rented from the private operators. Very often the making up or breaking up of the unit trains takes place at the stations that do not belong to the main-line railway. Under these conditions the attention to the economic methods development of the efficiency estimation of the unit train transportation has been increased. For example, in the work [11] a method of determining the effectiveness of unit train technology for the railway was presented. Expressions for the estimation of the unit train efficiency that takes into account the interests of the individual participants in the transportation process were proposed in [12]

$$\begin{cases} E_s = \Delta n e_{nH} - E_s^{add} \pm K_s \geq 0 \\ E_r = N e_{nH}^{av} \sum r + E_i + E_f + E_{ls} + E_{us} \pm K_r \geq 0 \\ E_c = -E_c^{add} \pm K_c \geq 0 \end{cases} \tag{6}$$

where: E_s, E_r, E_c – are the economy of expenditures of the shipper, the railway and the consignee correspondingly; Δn – is a reduction of the operational fleet of the freight cars involved in the transportation, as compared to the dispatch of the collective car dispatch; E_s^{add}, E_c^{add} – are the additional reduced expenditures of shippers and consignees related to the performing of initial and finite operations on the making up and breaking up of the train traffic volumes at their app roach lines correspondingly; E_i, E_f – are the reduction of operation costs of the connecting stations to the approach lines of the loading and unloading in connection with the transfer of performing the initial and finite operations to the approach lines, as well as the elimination of car delivery-removal by shunting locomotives; $E_{ls,}$ E_{us} – are the reduction in operation costs of railways in connection with the lack of car transportation at the divisions adjacent to the loading and unloading stations in the assorted, clean-up and transfer trains correspondingly. K_s, K_r, K_c – are the reimbursement of additional costs related to the unit train transportation of the participant/to the participant of the transportation process (shipper, railway, consignee correspondingly).

However, the transportation of unit trains on the main-line network is performed by railway on the basis of solving the problem of increasing network-wide transport efficiency. The main principles of the decision of this problem by a railway were presented in the work [13]. It should be noted that this approach does not guarantee a reduction in the average duration of goods delivery and car turnover for an individual client. Partially this problem can be solved by the organization of unit train transportation by the schedule [14]. However, the results of researches that were presented in [15] indicate that in order to achieve sustainable interaction between railways and industrial enterprises, the additional time reserve should be included in the train schedule and the schedule for the turnover. This necessity reduces the effectiveness of this technology for customers.

The main disadvantage of the above-mentioned methodologies is that the definition of expenditures related to the use of the freight car fleet is carried out mainly by the calculation methods based on the average network standards. The error magnitude of such methods may be permissible during the development of the making up of the train plan for Ukrzaliznytsia (Ukrainian Railways); however, it may be critical for a particular shipper or consignee. Improvement of the estimation accuracy of the influence of car traffic volume organization methods on the utilization rates of freight cars may be achieved using the statistical data on transportation on certain routes. The purpose of the article is to develop the methodology for the estimation of the unit train effectiveness on the basis of statistical data.

3. METHODOLOGY

The movement duration of cars that are dispatched by both group and unit train shipments depends on a significant number of factors and is a random value. In this regard, estimation of the unit train effectiveness cannot be performed on the basis of comparison of the movement time of individual shipments. To solve the problem it is necessary to use the methods of mathematical statistics [16].

The potential opportunity of cargo unit train transportation at the particular route may be established on the basis of calculations, simulation modelling or analysis of the efficiency of transportation, which are close to the observed ones in its conditions. It is proposed to perform the final check of efficiency on the basis of full-scale experiments.

This study was carried out using the example of the organization of car traffic volumes in the logistic chain of iron ore raw material supply (pellets) from the Poltava Mining and Concentrating Company (MCC) to the transport node Transinvestservice (TIS), which includes a private industrial station Khimicheskaya. Prospective volumes of pellet transportation are up to 5 million tons per year. Services of pellet transportation are carried out by private cars. At this, the loaded cars are dispatched by the unit train and the empty ones are not. As a result of the processing of information on the location and status of the cars, their turnover was defined with division according to its individual elements. Results of the processing are presented in Table 1.

Analysis of the data from Table 1 shows that at the existing organization of car traffic volumes the car turnover is θ = 107.12 hours or 4.46 days. At the same time, the duration of the loaded car running is lesser for 10.2 hours than that of the empty car. Improving the efficiency of pellet transportation from Poltava MCC to the transport node TIS can be achieved by delivering the empty cars by unit trains. With the existing transportation technology (see. Fig. 1, *a*) at the approach line of TIS (Khimicheskaya station), in view of the track capacity deficit, there is a performance of the accumulation of transfer trains that arrive for processing at the marshalling yard Chernomorskaya, where the accumulation of trains to the destination station Zolotnishino takes place.

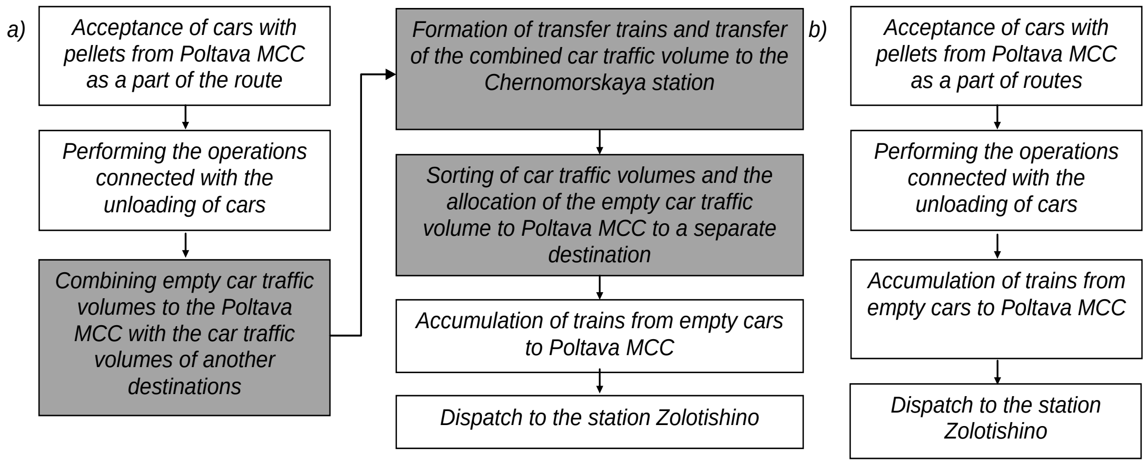
Table 1

Location and status of cars

No.	Element of the car turnover	Duration, h
1	Running of the loaded car from the station Zolotnishino (Poltava MCC) to the station Chernomorskaya (TIS)	26.12
2	Standing of the cars at the approach line (including unloading of cars) until handover of the empty car to the railway	23,72
3	Running of the empty car from the station Chernomorskaya (TIS) to the station Zolotnishino (Poltava MCC)	36.32
4	Standing of the cars at the approach line of Poltava MCC (including loading of cars) until handover of the loaded car to the railway	20.96
Total		107.12

Making up of the unit trains of empty cars with destination station Zolotnishino directly at the Khimicheskaya station reduces operations related to the car processing at the gravity hump associated with their processing upon arrival and departure, as well as eliminates the change of train locomotives at the station Chernomorskaya (see Fig. 1, *b*). Figure 1*a* shows operations that are eliminated when an empty car will be delivered to the Poltava MCC by unit trains. This ensures the reduction in turnover of cars, an increase in their productivity, and a reduction of damages at the gravity hump.

Changing the system of organization of empty car traffic volumes that are dispatched from the TIS to Poltava MCC affects the idle hours of the cars in the system "Khimicheskaya station – Chernomorskaya station".



a) existing technology; *b)* by unit train
а) существующая технология; *b)* в условиях маршрутизации

Fig. 1. Operations performed with the cars of Poltava MCC at the St. Khimicheskaya and St. Chernomorskaya
Рис. 1. Операции, выполняемые с вагонами Полтавского ГОКА на ст. Химическая и ст. Черноморская

To estimate the unit train technology's influence of the empty car transportation on the value of idle hours of cars in the given system, within 23 days a full-scale experiment was carried out on the making up of unit trains at the station Khimicheskaya (TIS) and dispatching them to the Poltava MCC. As an alternative, the results of work for 13 days before and 14 days after the experiment were analyzed. As a result, two samples were obtained of the time values of car groups standing in the system "Khimicheskaya station – Chernomorskaya station". They are: $X = \{x_1, x_2, \ldots, x_{n_X}\}$, corresponding to the new technology of transportation of empty cars by unit trains (sample volume is $n_X = 143$) and $Y = \{y_1, y_2, \ldots, y_{n_Y}\}$, corresponding to the existing transportation technology (sample volume is $n_Y = 123$).

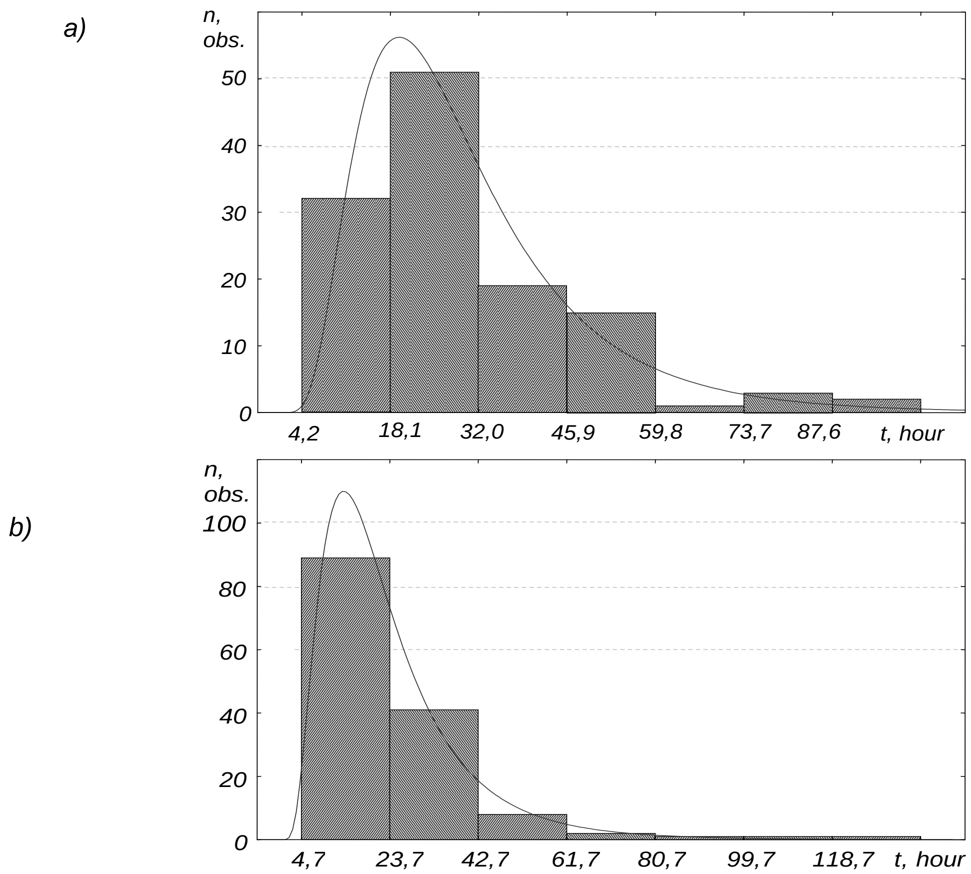
To determine the parameters of random variables corresponding to the samples X and Y, their statistical processing is performed. According to the results of the processing, the histograms of corresponding distributions are constructed (Fig. 2).

On the basis of the statistical processing of these samples, statistical estimations of the mathematical expectations $\bar{x}$ and $\bar{y}$ were obtained [16], as well as the mean-square deviations s_x and s_y.

At this the mathematical expectation of the total standing time of empty cars in the system "Chernomorskaya station – Khimicheskaya station" in the conditions of unit train delivery of the empty car traffic volumes is $\bar{x} = 23.7$ h ($s_X = 17.7$ h) and with the existing technology – $\bar{y} = 30.0$ h ($s_Y = 17.3$ h).

Given the form of histograms (see Fig. 2) during the study, the hypotheses H_X and H_Y that the random variables X and Y have a log-normal distribution were made:

$$H_X:\ F_X(x) = \mathrm{f}(\ln\ x; \mu_X; \sigma_X^2),\ x \geq 0, \tag{7}$$



a) transportation of empty cars by unit trains; *b)* existing technology
а) перевозка порожних вагонов маршрутами; *б)* существующая технология перевозки

Fig. 2. Histograms and functions of the random variable distribution density of the standing time of the car in the system "Khimicheskaya station – Chernomorskaya station"
Рис. 2. Гистограммы и функции плотности распределения случайной величины времени нахождения вагона в системе «станция Химическая-станция Черноморская»

where: $\mathrm{f}(z;\ \mu_X;\ \sigma_X^2)$ – is a function of the normal distribution of the random variable Z=ln X with par ameters (μ_X; σ_X^2);

$$H_Y:\ F_Y(y) = \mathrm{f}(\ln\ y; \mu_Y; \sigma_Y^2),\ y \geq 0, \tag{8}$$

where: $\mathrm{f}(w;\ \mu_Y;\ \sigma_Y^2)$ – is a function of the normal distribution of the random variable W=ln Y with par ameters (μ_Y; σ_Y^2).

To test the hypotheses H_X and H_Y the chi-squared test χ^2 was used:

$$\chi^2 = n\sum_{i=1}^{r}\frac{(p_i^* - p_i)^2}{p_i}, \tag{9}$$

where: p_i, p_i^*– are the theoretical and statistical possibilities of a random variable falling into the i-th category that is calculated at the accepted hypothesis about the distribution law corresponding ly; n – is a total number of observations.

At the selected level of significance (α= 0.05) and the number of freedom degrees (ν=4), a comparison of the calculated values of the Pearson criterion χ^2 for the samples X and Y with their critical values $\left(\chi^2_{\max} = 7{,}80\right)$ shows that the available results of the field studies do not contradict the made hypotheses H_X and H_Y: $\chi^2(X)$=3.94< 7.80 and$\chi^2(Y)$=1.21< 7.80. Thus, it can be concluded that the random value of car standing time in the system "Khimicheskaya station – Chernomorskaya station" during dispatching by unit trains (value X) and by groups of cars (value Y) are subordinated to the log-normal distribution law [16] and have the density function of the following type:

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{\frac{\left(\ln(x)-\mu\right)^2}{2\sigma^2}}, \tag{10}$$

where: μ – is a scale parameter; σ – is a form parameter.

The values μ and σ for the samples that characterize the cars standing in the system "Khimicheskaya station – Chernomorskaya station" are presented in Table 2.

Table 2

Log-normal distribution parameters of the random value
of car standing time in the system "Khimicheskaya station – Chernomorskaya station"

Parameter	Sample$X$ (experiment)	Sample$Y$ (existing organization)
μ	2.977	3.2559
σ	0.5998	0.5405

To determine the unit train efficiency of empty car transportation, a verification of the significant difference of the obtained samples X and Y of the car standing time in the system "Khimicheskaya station – Chernomorskaya station" was carried out. Thus, it was made a hypothesis H_0 that these samples belong to different parent populations having different distribution functions ($F_X \neq F_Y$) and competing hypothesis H_1: $F_X = F_Y$.

To test the hypothesis about the difference between the two samples X and Y with the volumes n_X= 143 and n_Y= 123, respectively, the Wilcoxon criterion was used. The meaning of Wilcoxon criterion is determined using the expressions:

$$u_X = R_X - \frac{n_X(n_X+1)}{2}, \tag{11}$$

$$u_Y = R_Y - \frac{n_Y(n_Y+1)}{2}, \tag{12}$$

where: R_X, R_Y – is the sum of ranks corresponding to the elements of samples X and Y.

Ranks $r_i(r_j)$ are the numbers of the elements of both samples in ascending order ($r\in[1, n_x+n_y]$). As a result of calculation of the above mentioned statistics for the samples X and Y, the values R_X = 16592, u_X = 6296 and R_Y = 18919, u_Y = 11293 were obtained.

When testing the hypothesis H_0: $F_X \neq F_Y$ against the competing hypothesis H_1: $F_X = F_Y$, a double-sided critical region is accepted; at this the hypothesis H_0 is accepted if min(u_X, u_Y) $< U_{n_X,n_Y,\alpha}$. For larger values $n=n_X+n_Y$, approximate critical value $U_{n_X,n_Y,\alpha}$ can be defined as

$$U_{n_X,n_Y,\alpha} \approx \frac{1}{2}n_X n_Y - \lambda_q\sqrt{\frac{1}{12}n_X n_Y(n_X+n_Y+1)}, \tag{13}$$

where: λ_q – is a quantile of order q of the normal distribution N (0;1).

Quantile q is determined by the accepted level of significance

$$q = 1 - \frac{\alpha}{2}, \tag{14}$$

where: α – is a level of significance (it is accepted α = 0.05).

For the observed samples X and Y: n=143+123=266, q=1–0.05/2=0.975, $\lambda_{0.975}$=1.960; then $U_{n_X,n_Y,\alpha} = 7567{,}86$. Since min ($u_X$, u_Y) = 6296 > 7567.86, the basic hypothesis H_0 on the belonging of the samples X and Y to different parent populations does not contradict the experimental data and can be accepted.

Thus, it can be concluded that in the case of the unit train implementation for the transportation of empty pellet cars [12], the time of their standing in the system "Khimicheskaya station – Chernomorskaya station" is different from the standing time of the existing technology. Furthermore, since the rank sum of the sample *Y* (R_Y = 18919) exceeds the rank sum of the sample *X* (R_X = 16592), it follows that the standing time of the empty cars in the system at the existing technology, in general, exceeds this time at the unit train implementation.

Idle hours of cars at the approach line of TIS and Chernomorskaya station are under the influence of a significant number of random factors [17], including the unaccounted ones. These factors include idle-time because of the damage to cars, idle hours because of conducting operations on the railway, etc. Such idle hours correspond to a small number of cars, but because of its considerable importance it significantly affects the mathematical expectation of a random variable of the total standing time of cars in the system "Khimicheskaya station – Chernomorskaya station". Therefore, for further analysis, the values that do not exceed the upper limit were used. They were set with the reliability of 0.99. The corresponding maximum values and parameters of the corrected samples are represented in Table 3.

Table 3

Corrected samples for analysis of the movement duration of cars
at the direction TIS – Poltava MCC

Parameter	Sample*X* (experiment), h	Sample *Y* (existing technology), h
Upper limit	79.23	91.22
Sample size	140	121
Mathematical expectation	21.92	28.86
Mean-square deviation	12.30	15.08

The duration of car standing reduction in the system "Khimicheskaya station – Chernomorskaya station" is a random variable Δ.

Mathematical expectation of the given value can be defined as:

$$\overline{\Delta} = \overline{y} - \overline{x}\,, \tag{15}$$

Mean-square deviation can be defined as:

$$s_\Delta = \sqrt{s_x^2 + s_y^2}\,, \tag{16}$$

On the basis of the data from Table 2 the parameters of random variable Δ are established

$$\overline{\Delta} = 28{,}86 - 21{,}92 = 6{,}94 \text{ h},$$

$$s_\Delta = \sqrt{12{,}30^2 + 15{,}08^2} = 19{,}46 \text{ h}.$$

To determine the distribution type of random variable Δ, there were modelled 300 values of this variable as the difference between the values of random variables *Y* and *X*. Statistical analysis shows that there is no reason to reject the hypothesis of normal distribution of the variable Δ

On the basis of calculated parameters of the random variable Δ, the confidence interval for the mean value was defined using the formula:

$$\delta = \frac{t s_\Delta}{\sqrt{n}}\,. \tag{17}$$

The table value t=1.96 corresponds to the reliability level 0.95. At the same time, the confidence interval for a sample volume of n=121 is:

$$\delta = \frac{1{,}96 \cdot 19{,}46}{\sqrt{121}} = 3{,}47 \text{ h}.$$

Thus, on the basis of the experiment, it can be argued that the reduction in standing time of cars in the system "Khimicheskaya station – Chernomorskaya station" is within Δ_{min} = 6.94–3.47=3.47 hour and Δ_{max} = 6.94+3.47=10.41 hour.

The effect from the unit train delivery of the empty car traffic volumes is defined for the average reduction in the duration of car turnover Δ = 6.94 hours (expected effect), and for the minimum reduction in car turnover that is confirmed by the results of the experiment Δ_{min} = 3.47 hour (minimum effect).

4. INVESTIGATION RESULTS

Economy of the shipper associated with a reduction in the need for cars involved in the transportation of pellets when empty car traffic volumes are delivered by unit trains can be determined by the formula:

$$E_{cf} = \frac{k_n k_f Q_{ann} \Delta_{\theta} e_{hH}}{q_{st}}, \tag{18}$$

where: Q_{ann} – is a promising annual volume of pellet transportation (5 million tons per year); k_f – is a safety factor that takes into account the proportion of defective cars, k_f =1.04; Δ_{θ} – is time saving according to car turnover; q_{st} – is a static norm of pellet loading.

The economy of the railway associated with the elimination of yard operations at the station Chernomorskaya is determined by the formula:

$$E_n = \frac{Q_{ann}}{q_{st}}\left(e_p + \frac{e_l}{m}\right), \tag{19}$$

where: e_p – is an expenditure rate for the yard operations for one car at the station Chernomorskaya, USD /car-h; e_l – is an expenditure rate for the locomotive change at the station Chernomorskaya, USD /car-h.

For the accumulation of cars for unit trains at the station Khimicheskaya (TIS), it is necessary to construct and maintain an alternate track. Reduced costs associated with this are about 150 thousand USD per year. Total indicators of economic efficiency for unit train technology are shown in Table 4.

Table 4

Technical and economic indicators of efficiency for the unit train delivery of empty car traffic volumes

Indicator	Participant of the transportation process	Expected value,	Minimal value
Reduction of expenditures to rent the cars for transportation	Poltava MCC	720.0	365.0
Reduction of expenditures for car processing and locomotive changing at the station Chernomorskaya	Ukrzaliznytsia	487.5	487.5
Increase of expenditures for the construction and maintenance of additional track capacity	TIS	150.0	150.0

In general, the expected reduction in the value of logistics costs in the supply chain is 1.058 mln. USD per year. At this it can be argued with a reliability of 0.95 that the cost savings would be no less than 0.703 mln. USD per year. In addition, it should be noted that the effect of unit train delivery is unevenly distributed among the participants of the transportation process. At the same time, the expenditure economy of Poltava MCC and Ukrzaliznytsia is achieved by the expenditure increase of the transport node TIS. In this regard, in order to make the unit train usage profitable for all participants of the transportation process, the development of compensatory measures for the TIS from Ukrzaliznytsia and Poltava MCC is required.

5. CONCLUSION

According to the research results, one can make the following conclusions:

1. The disadvantage of existing methodologies for efficiency estimation of the unit train transportation is that the definition of expenditures related to the use of the freight car fleet is carried out mainly by the calculation methods based on the average network standards. Improvement of the estimation accuracy of the influence of car traffic volume organization methods on the utilization rates of freight cars may be achieved using the statistical data on transportation on certain routes.
2. To determine the efficiency of unit trains, a methodology based on a full-scale experiment and statistical processing of its results was proposed. This approach makes it possible to obtain a probabilistic estimation of the efficiency of rolling stock use at different approaches to the organization of car traffic volumes, as well as to define the effect for each of the participants in the transportation process.

References

1. *Encyclopedia Britannica*. Available at: http://global.britannica.com/EBchecked/topic/615316/unit-train
2. Association of American Railroads. *A Short History of U.S. Freight Railroads*. 2012. Available at: http://webcache.googleusercontent.com/search?q=cache:i4WY1oTw9mEJ:doc.xueqiu.com/140ee8850e0713fb6872f0e2.pdf+&cd=1&hl=ru&ct=clnk&gl=ua
3. Осипов, В.Т. *Маршрутизация перевозок и повышение ее эффективности. Научное издание*. 1967. No. 2. P. 68-93. [In Russian: Osipov, V.T. *Routing of transport and improving its efficiency*. *Scientific publication*].
4. Keseljevic, C. The problems of freight traffic on the Railways of France. *Railways of the world*. 2002. No. 7. P. 22-25.
5. Gerrard, B.M. & McTierman, E. Regulation of Movement of Crude Oil by Rail in New York. *New York law journal*. 2015. No. 90. P. 254-255.
6. Frittelli, J. U.S. Rail Transportation of Crude Oil: Background and Issues for Congress. *Congressional Research Service.* 2014. P. 2-25.
7. Kenkel, P. *An Economic Analysis of Unit-Train Facility Investment*. Department of Agricultural Economics, Oklahoma State University. 2004. P. 3-14.
8. Schlake, B.W. & Barkan, C.P.L. & Edwards, J.R. Impact of Automated Inspection Technology on Unit Train Performance. *Proc. Joint Rail Conference*. 2010. Urbana.
9. Jung, J. U & Kim, H. S. Strategies for Improving the Profitability of a Korean Unit Train Operator: A System Dynamics Approach. *Advances in Swarm and Computational Intelligence*. 2015. P. 275-283.
10. Інструктивні вказівки з організації вагонопотоків на залізницях України. Киев. ТОВ «Швидкий рух». 2005. 100 p. [In Ukrainian: Description of organization of car traffic volumeson the Railways of Ukraine. *OOO "Fast motion"*].
11. Осьминин, А.Т. & Никифорова, О.А. Определение эффективности организации маршрутов с мест погрузки в современных условиях. Вестник Ростовского государственного университета путей сообщения. 2008. No. 1. P. 91-100. [In Russian: Osminin, A.T. & Nikiforova, O.A. Determination of efficiency of the organization of routes from shipping places in modern conditions. *The Bulletin of the Rostov state transport university*].
12. Верлан, А.И. Совершенствование методов стимулирования отправительской маршрутизации на железнодорожном транспорте. *Наука и прогресс транспорта*. *Вестник*

Днепропетровского национального университета железнодорожного транспорта. 2014. No. 1(49). P. 75-85. [In Russian: Verlan, A.I. Stimulation methods improvement of exit route on railway transport. *Science and transport progress*. *Dnipropetrovsk National University of Railway Transport*].

13. Кужель, А.Л. & Шапкин, И.Н. & Вдовин, А.Н. Информационно-аналитические технологии оперативной корректировки и контроля выполнения плана формирования поездов. *Железнодорожный транспорт*. 2011. No. 7. P. 13 -20. [In Russian: Kuzhel, A.L. & Shapkin, I.N. & Vdovin, A.N. Information and analytical technologies of expeditious adjustment and control of implementation of the plan of formation of trains. *Railway transport*].
14. Шапкин, И.Н. & Самойлова И.М. О переходе к технологии организации движения грузовых поездов по расписанию. *Железнодорожный транспорт*. 2012. No 3. P. 14-17. [In Russian: Shapkin, I.N. & Samoylova, I.N. O transition to technology of the organization of the movement of cargo trains on the schedule. *Railway transport*].
15. Бобровский, В.И. & Козаченко, Д.Н. & Божко, Н.П. & Рогов, Н.В. & Березовый, Н.И. & Кудряшов, А.В. *Оптимизация режимов торможения отцепов на сортировочных горках*. Днепропетровск: Ю.В. Маковецкий, 2010. 260 с. [In Russian: Bobrovskiy, V.I. & Kozachenko, D.N. & Bozhko, N.P. & Rogov, N.V. & Berezovy, N.I. & Kudryashov, A.V. Optimization of braking modes for unhooks on hump yards. Dnepropetrovsk: Y.V. Makovetskii, 2010. 260 p.]
16. Вознесенский, В.А. *Статистические методы планирования эксперимента в технико-экономических исследованиях. Научное издание*. 1974. 192 p. [In Russian: Voznesensky, V.A. *Statistical methods of experiment planning in feasibility studies. Scientific publication*].
17. Баланов, В.О. Анализ факторов, влияющих на обеспечение движения грузовых поездов по расписанию. *Збірник наукових праць Дніпропетровського національного університету залізничного транспорту імені академіка В. Лазаряна. Транспортні системи та технології перевезень.* 2015. No. 10. P. 5-9. [In Russian: Balanov, V.O. Analysis of factors affecting the provision of freight Trains on timetable. *Collection of scientific works of Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan. Transport systems and transport technologies*].

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