Production estimate of technological operations duration in railway transport

Ziyoda Mukhamedova*, *Zakhro* Ergasheva, *Jamshit* Barotov, *Vasilya* Ergasheva, and *Rustam* Abdullaev

Tashkent State Transport Universitet, Tashkent, Uzbekistan

Abstract. Purpose: To stabilize the departure of trains on schedule, to do this, to justify the size of the factor of unevenness taken into account when normalizing the duration of the main technological operations with the compositions of container block trains for departure at the junction stations. Methods: From the existing automated systems, statistical data were collected and processed using MS Excel software, and the mathematical expectation, standard deviation, and dispersion of the duration of operations with the block train at the departure station were determined. The hypothesis about the normal law of distribution of the random variable of the duration of each of the main operations at the station was tested by the "chi-square" goodness-of-fit test. Results: The distribution of the random variable of the duration of operations at the station is described using the normal distribution law; a technological schedule for processing the composition of the container block train on the tracks of the railway junction station was built. Practical significance: Practical recommendations will reduce the technological norms for the processing time of a container block train on the tracks of a railway junction station. As a result, the processing time for block trains on departure on the station tracks will be reduced from 154 minutes to 132 minutes, which will save time by 22 minutes.

1 Introduction

The train moving traffic is realized according to a strict schedule. Depending on the railway transportation contract's terms, the shipped cargoes are transported by local or direct traffic.

Regarding transportation by local traffic, the train delivers the cargo within the same railway. In the case of direct transportation, two or more railway systems are used to deliver cargo, which makes up a unified railway network [1].

Cargoes are transported in wagons and containers belonging to the railway transport office or in wagons owned or rented by legal entities or individuals.

The consignee must be notified of the cargo arriving at his address no later than noon on the day following the arrival of the cargo. The consignee must pay the carrier for transport services.

The system of the railway station operation includes the order and sequence of

*Corresponding author: mziyoda@mail.ru

processing trains and wagons. At that, the most optimal use of technical means should be ensured, considering modern technologies and full-time employees of the station. Staff members include compilers, inspectors, and acceptors.

To draw up a system of railway operation, the following steps must be envisaged:
1) a set of technical operations;
2) chronological sequence of operations;
3) the timing of each operation;
4) the funds necessary to conduct each operation;
5) employees responsible for the implementation of each operation [2].

Rail transport efficiency depends on the precise organization of train traffic, which should ensure the required cargo turnover, the best use of technical means, and train traffic safety. The duration of the operation cycles of loading trains, delivering cargo, unloading at the destination, and returning empty cars to the place of loading should be minimal. In contrast, the cargo should move smoothly following the schedule [3].

2 Methods

From the existing automated systems, statistical data were collected and processed using MS Excel software, and the mathematical expectation, standard deviation, and dispersion of the duration of operations with the block train at the departure station were determined. The hypothesis about the normal law of distribution of the random variable of the duration of each of the main operations at the station was tested by the "chi-square" goodness-of-fit test.

3 Results and Discussion

The functioning of any transport system, including a railway locomotive, can be represented as a chronological sequence of events. Modeling such a system is discrete; that is, it involves interruptions in the operation of the train and the railway station.

Let us highlight the operations carried out in the departure yard:
1) operations of coupling and uncoupling of a railway locomotive;
2) technical and commercial inspection;
3) implementation of repairs without uncoupling;
4) elimination of detected malfunctions;
5) preparation of documentation and their transfer to the train crew;
6) testing of automatic brakes operation;
7) implementation of dispatch operations.

According to the technological process of the station, the time for processing a cargo train with a change of locomotives is given in Table 1.

Table 1. Cargo train processing with a change of locomotives

№	Operation	Time to complete, minutes
1	Notification of employees of the railway fleet about the number, approach track, and time of arrival of the train	1
2	Access to approach track to workers involved in the processing of the train to meet it "on the go"	1
3	Fixing the composition of the train, accepting transport documents from the locomotive driver	9

Continuation of table № 1

№	Operation	Time to complete, minutes
4	Uncoupling a train locomotive and its leaving it from the approach tracks	5
5	Locomotive arrival on the track and its coupling to train	5
6	Fencing of a train using hand-held portable signals	17
7	Charging the train brake line	15
8	Full approbation of the train brakes and, if necessary, additional troubleshooting work. Hanging tail signals, readiness report	40
9	Acceptance of wagons of a train with dangerous and nomenclature cargoes under the protection	30
10	Removing the fence	17
11	Removing the means of train fixing	9
12	Delivery of transportation documentation to the locomotive crew, departure of the train	5
Total duration, min		154

The need to comply with a single network-wide train schedule requires the coordinated interaction of all offices of the railways. The movement of trains strictly according to the schedule is ensured by the correct organization and precise implementation of the technological operation process of stations, depots, traction substations, maintenance points, and other units associated with the train traffic [4].

The technology of a container block train at railway terminals is considered in the article. Figure 1 shows the technology for processing a container block train when organizing its movement on the railway network [5-7].

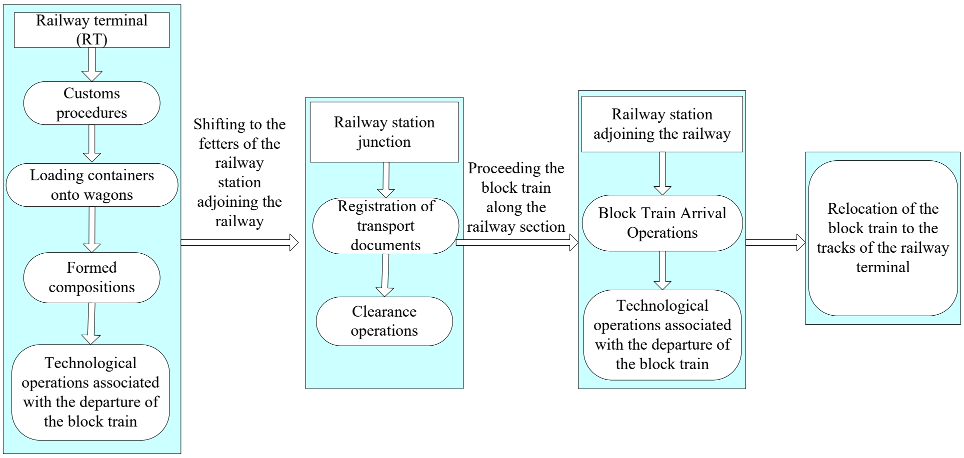

Fig. 1. Technology for processing a container block train when organizing its movement on the railway network

Customs operations and cargo operations with a container block train are conducted at the railway terminal; there, technical and commercial inspections are carried out by employees of the technical inspection points and the commercial inspection points; the station employees check the correct placement of containers on fitting platforms and accept cargo for departure. In total, about 400 minutes are spent on all operations performed [8].

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No later than one hour before the arrival of the train locomotive, the container block train is placed on the track of the departure station. The train locomotive is then coupled to the train, the brakes are checked, and the container block train leaves the station on a fixed schedule.

The technological schedule for processing the container block train for departure from the connecting station of the railway terminal is shown in Table 2.

Table 2. Technological schedule for the processing of the block train for departure from the connecting station of the railway

№	Operation	Time, min
1	Notification of employees of the STC, PTO VChDE-13, FGP VO, DSPP 1 yard about the number, arrival time, train approach track	0
2	Access to the approach track to workers involved in the processing of the train for a meeting "on the go"	0
3	Fixing the train, acceptance of a package of transportation documents from the locomotive driver	8
4	Uncoupling a train locomotive and its leaving the approach track	4
5	Locomotive arrival on the track and its coupling to train	4
6	Fencing the train with hand-held portable signals	15
7	Charging train brake line	13
8	Complete testing of train brakes, additional troubleshooting work, hanging tail signals, and readiness report	30
9	Acceptance of wagons with nomenclature and dangerous cargo under the protection	30
10	Removing the fence	15
11	Removing the means of fixing the train	8
12	Delivery of a package of transportation documents to the locomotive crew, warnings, departure	5
Total duration, min		132

The generality and the total number of similar objects or phenomena, united by some common feature, constitute the general population. For example, we are interested in meeting the deadlines for processing a train at departure stations. Thus, all trains processed at the station make up the general population. The observations aim to investigate the attributes of the objects of interest in the general complex. If it were possible to explore all the relevant objects of the complex, this problem would be solved easily. Often such studies, with a large volume or number of units, require serious labor or material costs.

In such cases, for observation, a finite number of objects are taken and examined from the general complex using the statistical selection method and random sampling.

A set of objects randomly selected for observation is called a selected set or sample. The calculated values of the characteristics of the selected set make it possible to judge the values of the entire general complex.

To ensure the reliability of these conclusions, the following conditions should be met:

1) the sample should contain an adequate number of observable objects;

2) observable objects should reflect the general complex; they should have common characteristics with this complex.

With an increase in the number of observations (sample size), the characteristics of the number of the selected set (the mean value of the feature, its variance, etc.) approach the characteristics of the general complex.

Having processed the statistical data on the departure trains, the number of observations in sample n can be determined by the formula:

$$n \geq \frac{X^2}{4 \cdot \mu^2} \quad (1)$$

where X is obtained from the table of values of the integral, depending on the obtained reliability $P = F(x)$ or in scientific research, P = 0.90 is often taken [9]. Following [10], $X = 1.65$ for the accepted reliability of observations $R = 0.90$, and the degree of accuracy R=0.05.

In this case:

$$n \geq \frac{1.65^2}{4 \cdot 0.05^2} = 273$$

Based on this, the sample size (total number of observations) should consist of at least 273 objects. For the sample to reliably indicate the features of the general complex, each observation unit must be taken approximately, not selectively, but randomly.

If the objects of the general complex are moving and their random selection is ensured, then any sequence (consistency) of n objects can enter the sample. Since the time taken for the arrival of any cargo in a wagon shipment is a random event (value), a sample of n wagons sent in a row is selected to define the average delivery time.

Using mathematical-and-statistical methods (MSM) [11, 12], based on the number of objects (n) of the general complex, the sample size is determined as:

$$C = \frac{t_{max} - t_{min}}{K} \quad (2)$$

Depending on the sample range, its rate is defined as follows:

where max min *t, t* are the largest and smallest values of the time between observations, respectively. In the case under consideration, they are the maximum/minimum time spent on processing the train, and hours, respectively. The processing of a train upon departure is considered an example of a technological process in a departure station based on the MSM. According to (1), the number of observation objects should be at least 273.

The statistical information elements processed in the study were 310 in total. This, in turn, shows that the selected data is sufficient. Therefore, based on (2), it is possible to determine the sample range:

$$K = (1 + 3.322 \cdot \ln(n)) = 9.27 \quad (3)$$

The maximum/minimum time spent on the railcar delivery between observations was 220 and 82 hours, respectively. Thus, based on (2), the sample rate can be determined as:

$$C = \frac{220 - 82}{9.27} \approx 15$$

Let us define the boundaries (limits) of the delivery rate. The whole research process using statistical and mathematical methods is performed based on information from Table 3. Here, the small boundary value of the first-rate is determined in the following order (Table 3, column 2).

Therefore, the large boundary value of the first-rate is

$$h_{1min} = t_{min} - \frac{C}{2} = 82 - \frac{15}{2} = 74.5$$

Thus, the boundaries of the first-rate are within the following range 74.5÷89.5.

$$h_{1min} = 74.5 + C = 74.5 + 15 = 89.15$$

Table 3. The results of the study of train processing upon departure at the connecting stations of the railway terminal based on the normal distribution law

№	Rate value, h_i		Average rate value, tav(i)	Number of observations in a series, n_i	Statistical frequency, pc(i)
1	2		3	4	5
1	74.5	89.5	82	8	0.03
2	89.5	104.5	97	18	0.06
3	104.5	119.5	112	35	0.116
4	119.5	134.5	127	58	0.19
5	134.5	149.5	142	62	0.206
6	149.5	164.5	157	53	0.176
7	164.5	179.5	172	33	0.12
8	179.5	194.5	187	21	0.07
9	194.5	209.5	202	10	0.022
10	209.5	224.5	217	2	0.01
Total	---	----	---	300	1.0000

Continuation of table № 3

№	tav(i) ·pc(i)	tav(i)2 ·pc(i)	Probability in the rate, ph(i)	Number of theoretical observation in rates f_i	$\frac{(n_i - f_i)^2}{f_i}$
1	6	7	8	9	10
1	2.186666667	179.3066667	0.0219	6.57	2.0449
2	5.82	564.54	0.0579	17.37	0.3969
3	13.06666667	1463.466667	0.1168	35.04	0.0016
4	24.55333333	3118.273333	0.179	53.7	18.49
5	29.34666667	4167.226667	0.2086	62.58	0.3364
6	27.73666667	4354.656667	0.1849	55.47	6.1009
7	18.92	3254.24	0.1247	37.41	19.4481
8	13.09	2447.83	0.064	19.2	3.24
9	6.733333333	1360.133333	0.0249	7.47	6.4009
10	1.446666667	313.9266667	0.0074	2.22	0.0484
Total	142.9	21223.6	1.0000	297.03	---

Accordingly, the boundaries of the second rate are in the range of 56.5÷69.5, and of the third rate – in the range of 69.5÷82.5, etc.

The average delivery volume (Table 3, column 3) is defined as:

$$h_{av(i)} = t_{\min(i)} + \frac{t_{\max(i)}}{2} \qquad (4)$$

According to (4), the average value in the first-rate is 50, and in the second rate, it is 60, and so on.

The number of statistical observations in the delivery rate (Table 3, column 4), that is, the fulfillment of the processing of a train per each rate, can be determined using the Countif accounting function of Microsoft Excel.

The statistical frequency (SF) of delivery (Table 3, column 5) is defined as:

$$P_i = \frac{n_i}{\sum_{i=1}^{j} n_i} \quad (5)$$

For example, the SF frequency of the train processing in the first-rate is 8/300 = 0.026, and so on.

The average value characterizing the state of the statistical distribution series, i.e., in the case under study, the average statistical value of the fulfillment of delivery times is determined as follows:

$$t_{av} = \sum_{i=1}^{j} \cdot t_{av(i)} \cdot p_{c(i)} \quad (6)$$

where I is a digit number (i = 1, 2, ..., j).

Consequently, the average delivery time value based on (6) is 143 hours (Table 3, column 6).

The statistical variance describing the spread of the distribution series, i.e., the statistical variance of the fulfillment of the processing of the train in the case under study, is defined as:

$$D_t = \sum_{i=1}^{j} \cdot t_{av(i)}^2 \cdot p_{c(i)} - t_{av}^2 \quad (7)$$

Therefore, the statistical dispersion of the fulfillment of the processing of the train according to (7) is 803.19 hours.

The standard deviation describing the absolute deviation of the statistical series, i.e., in the case under study, the standard deviation of the fulfillment of the delivery time is determined as:

$$\sigma_t = \sqrt{D_t} \text{, hour} \quad (8)$$

Therefore, according to (8), the standard deviation of the fulfillment of the delivery time is 28.3 hours.

The observational data shown in columns 3 and 5 of Table 3 are presented in the form of a histogram (Fig. 2), and after calculating the numerical characteristics of the statistical series, we proceed to the selection of a distribution curve that more fully characterizes this distribution. The distribution that corresponds to this curve is called a theoretical distribution.

All of the above proves the possibility of determining the fulfillment or nonfulfillment of the processing of the train on departure based on the normal distribution law.

The choice of a pattern of the statistical distribution of a random variable with sufficient accuracy is based on the physical nature (essence) of the process or phenomenon under study. In this case, the histogram or polygon and the numerical characteristics of the statistical series can serve as an additional feature. For example, for the pattern of normal distribution of a random variable, the entire scatter (with an accuracy of one percent) $t_{av} \pm 3\delta_t$ will be located in this area.

The coordinates of the curve of theoretical distribution of a random variable, the probability of a random variable falling into a certain interval, that is, in the case under study, the probability of processing a container block train in a rate (Table 3, column 8), is determined by calculating its probability in the rate.

Based on the fact that the appearance of the polygon in the histogram in Figure 2 characterizes the normal distribution law, for the normal distribution law of a random value (Figure 2, red curve), the probability of its falling into a certain interval (pн(i)) is determined by the following formula:

$$P\left(h_{i(min)} \leq p_{h(i)} \leq h_{i(max)}\right) = F\left(h_{i(max)}\right) - F(h_{i(min)}) \quad (9)$$

where $F(h_i)$ is the function of the normal distribution law.

The probability of processing the container block train corresponding to the first-rate (Table 3, column 8) was determined according to formula (9):

$$P\left(74.5 \leq p_{h(i)}\right) \leq 89.5 = -0.011 - (-0.499) = 0.488$$

The correctness of the approximation following the normal distribution law of delivery deadlines was tested by K. Pearson's goodness-of-fit test (goodness-of-fit X^2 (chi-square)) [13,14-18].

The value of $X^2$is determined by the following formula (Table 3, column 10).

$$X^2 = \sum_{i=1}^{j} \frac{(n_i - f_i)^2}{f_i} \quad (10)$$

where f_i is the theoretical probability of finding a random variable in the i-interval, is the number of theoretical observations in the case under study in the rate (Table 3, column 9).

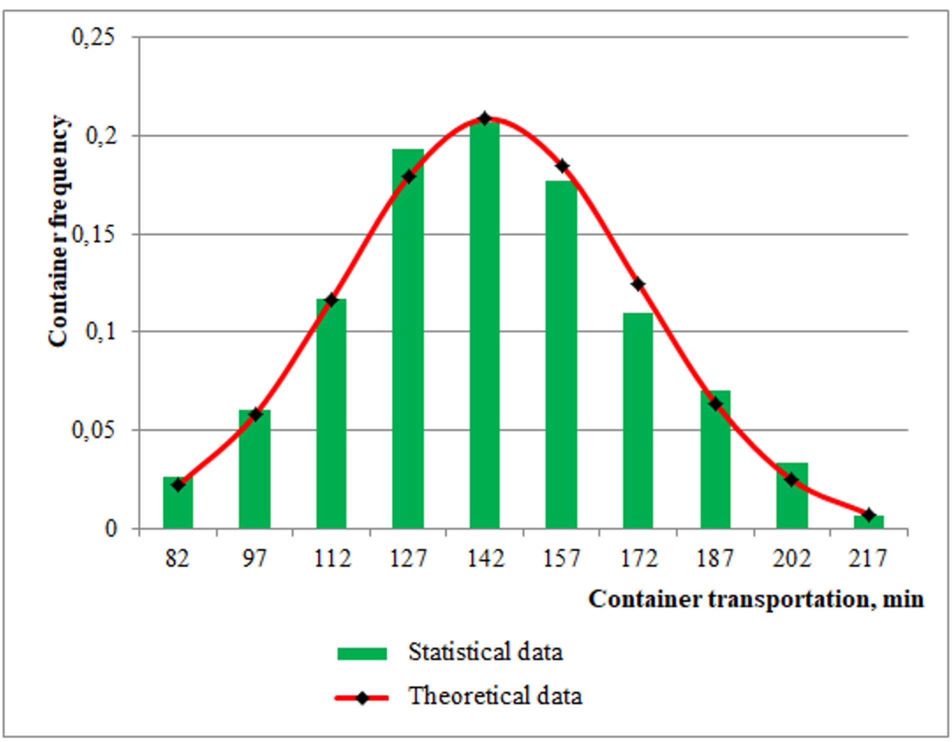

Fig. 2. Distribution histogram of a random variable for processing a container block train at the connecting stations of the railway terminal, min

As seen in Figure 2, the results of statistical-and-theoretical distributions obtained are close to each other. The results obtained according to statistical data almost coincide with those calculated by the normal distribution law.

Approximations of the mutual correspondence of statistical data and the theoretical normal distribution curve were realized per the V.I. Romanovsky criterion [19,20]. According to the V.I. Romanovsky rule

$$\frac{X^2-r}{\sqrt{2r}} \leq 3 \quad (11)$$

it is considered that the accepted distribution law satisfactorily describes the statistical distribution.

Here, r is the number of degrees of freedom:

$$r = k - s \quad (12)$$

where k is the number of group intervals; s is the number of independent conditions (for a normal distribution, $s = 3$ is taken [19]).

4 Conclusions

Based on the research using the normal distribution law, it can be concluded that the results obtained are reliable concerning the considered technologies for processing the container block train for departure at the connecting stations to the railway terminal. Thus, the time for technological operations with the cargo train is 154 minutes, and for the container block train, it is 132 minutes. The time reduction for processing a container block train at departure stations is due to implementing the main technological tasks and accumulating container trains at railway terminals, which, in turn, enables shippers to secure more reliable and expedited delivery of a wide range of containerized goods.

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