Optimization of the terminal operating mode during the formation of a container block train

Marufdjan Rasulov[*], *Masud* Masharipov, and *and Azizbek* Ismatullaev

Tashkent State Transport University, Tashkent, Uzbekistan

Abstract. Currently, container shipping plays an important role in international logistics. Terminals handle containers between different modes of transport and are a key element in supply chains. The quality of transport services, in general, depends on the technical and technological parameters of container terminals. At the same time, the task is to optimize the operating mode of the container terminal to reduce logistics costs. This article presents the results of a study of the traffic flows of terminals adjacent to the Tashkent regional railway junction stations, obtained based on timing observations on the unloading of containers arriving at the terminal by road for shipment by container trains. Based on these observations, the regularities of the distribution of the probabilities of the arrival of containers at the terminal and the time of servicing vehicles by a gantry crane were established. With the help of the established patterns, the main indicators were selected that characterize the quality of the container terminal functioning. A mathematical model has been developed and an algorithm for finding the optimal operating mode of a container terminal when forming a container block train. As the results of calculations have shown, the volume of logistics costs for the operation of a container terminal depends on the type and quantity of used handling equipment and the number of supply of fitting wagons to loading and unloading routes.

1 Introduction

In practice, container terminals often increase the demand for servicing the loading or unloading of containers with limited capabilities of the system of handling equipment, that is, when the throughput of the loading and unloading section of road transport is not able to meet all incoming requirements in the form of container ships. At the same time, the task of achieving minimum logistics costs is to establish a rational ratio between the number of servicing devices and the intensity of incoming requests.

To date, in most of the studied terminals, when choosing to lift and transporting equipment, they proceed from mathematical formulas [1-4], [8-11]. This approach leads to downtime for vehicles, and in some cases, downtime of lifting and transport machines. In this connection, in this study, the task of applying the queuing theory is posed, which makes it possible to establish the optimal duration of servicing a container terminal.

---

* Corresponding author: tashiit_rektorat@mail.ru

2 Methods and Materials

2.1 Method of studying the arrival of containers at the terminal

Simulation modeling has been used as a method for studying the flow of containers at the terminal. To study the characteristics of traffic flows, it is necessary to establish a distribution law for the receipt of container flows. At the same time, it is necessary to determine the following parameters by collecting and processing statistical data on the arrival of containers at the terminal by road:

- determination of the average number of containers arriving at the terminal during t:

$$m_x^* = \sum_{i=1}^{k} \overline{x_i} p_i^* \tag{1}$$

where $\overline{x_i}$ is average value of a random variable in the i-th digit; p_i^* s the frequency of hitting a random variable in the i-th digit; i is digit number ($i = 1, 2, …, k$).

- determination of statistical variance characterizing the dispersion of a distribution series D_x^* :

$$D_x^* = \sum_{i=1}^{k} x_i^2 p_i^* - (m_x^*)^2 \tag{2}$$

- determination of the statistical standard deviation characterizing the absolute deviation of the statistical series:

$$\sigma_x^* = \sqrt{D_x^*} \tag{3}$$

- to accept or refute the theoretical distribution, χ2 (chi-square):

$$\chi^2 = n \sum_{i=1}^{k} \frac{\left(p_i^* - p_i\right)^2}{p_i} \tag{4}$$

where p_i^*, p_i are respectively statistical and theoretical probabilities; n is total number of observations; i is digit number of statistical series ($i = 1, 2, … , k$).

- to assess the discrepancy between the statistical and theoretical distribution, the Romanovsky rule is applied:

$$\frac{\chi^2 - R}{\sqrt{2R}} \leq 3 \tag{5}$$

where: R is the number of degrees of freedom. It is determined by the number of bits k minus the number of independent conditions S imposed on the frequencies: $R=k-S$.

Below is the sequence for determining the mathematical expectation and the law of distribution of incoming traffic flow of vehicles with containers to the terminals of the Tashkent regional railway junction.

The calculations to determine the mathematical expectation and the distribution law of incoming flows of containers to the terminal adjacent to the railway station "T" are shown in Table 1.

From table 1 shows that the mathematical expectation averages 96 containers per day. A hypothesis is put forward about the subordination of the probability of the arrival of containers to Poisson's law. Moreover, $P(\chi^2) = 0.61$ at the significance level $\alpha=0.1$, $\chi^2_{0.1}=13.362$. Therefore, the inequality $\chi^2_{0.1} > \chi^2$ is satisfied, the hypothesis of the distribution to Poisson's law can be taken.

The histogram and hypothetical curve of the Poisson distribution density are shown in Figure 1.

Table 1. Probability distribution of containers arriving at the container terminal adjacent to station "T" (fragment of the table)

Number of containers arriving x_i	Observed frequency h_i	Statistical frequency p_i^*	Mathematical expectation $p_i^* \cdot \overline{x_i}$	Theoretical frequency p_i	χ^2
58-65	0	0.0000	0.0000	0.0005	0.1851
65-72	3	0.0083	0.5677	0.0061	0.2838
72-79	10	0.0276	2.0856	0.0375	0.9382
79-86	44	0.1215	10.0276	0.1257	0.0487
86-93	76	0.2099	18.7901	0.2412	1.4639
93-100	106	0.2928	28.2569	0.2759	0.3762
100-107	84	0.2320	24.0166	0.1947	2.5987
107-114	29	0.0801	8.8522	0.0873	0.2130
114-121	9	0.0249	2.9213	0.0255	0.0062
121-128	1	0.0028	0.3439	0.0050	0.3580
Total	362	1	95.8619	0.9993	6.4719

$R=10-2=8$; $m_x^* =\lambda\approx96$; $D_x^* =92.58$; $\sigma_x^* = 9.62$; $\chi^2\approx6.47$
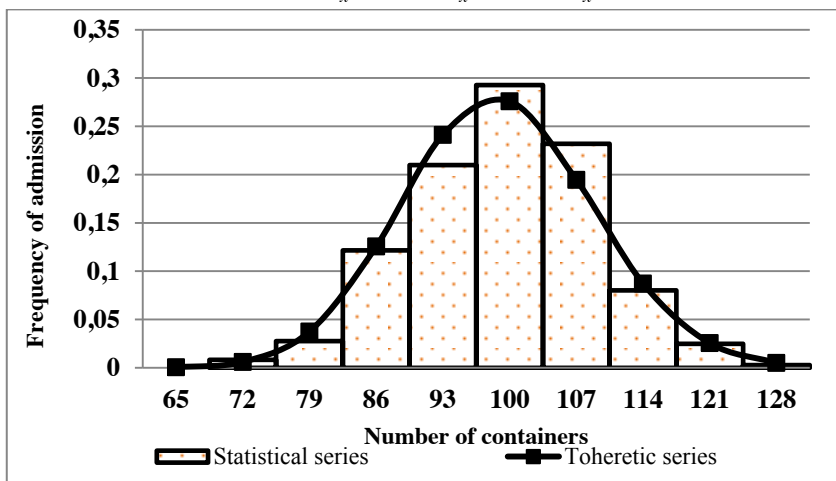
Fig.1. Histogram and hypothetical curve of the Poisson distribution density $\lambda=96$ con/day

The results of processing statistical data on the arrival of containers by road transport for dispatch by rail to the terminal adjacent to the station "Ch" are shown in Table 2.

Table 2. Probability distribution of containers arriving at the container terminal adjacent to station "Ch" (fragment of the table)

Number of containers arriving x_i	Observed frequency h_i	Statistical frequency p_i^*	Mathematical expectation $p_i^* \cdot \overline{x_i}$	Theoretical frequency p_i	χ^2
80-86	2	0.0056	0.4650	0.0090	0.4660
86-92	17	0.0476	4.2381	0.0351	1.5934
92-98	25	0.0700	6.6527	0.0927	1.9773
98-104	55	0.1541	15.5602	0.1702	0.5487
104-110	80	0.2241	23.9776	0.2220	0.0072
110-116	82	0.2297	25.9552	0.2092	0.7143
116-122	54	0.1513	18.0000	0.1449	0.0998
122-128	26	0.0728	9.1036	0.0748	0.0187
128-134	14	0.0392	5.1373	0.0292	1.2326
134-140	2	0.0056	0.7675	0.0087	0.3944
Total	357	1	109.8571	0.9959	7.0524

$$R=10-2=8; \quad m_x^* = \lambda \approx 110 \text{ cont}; \quad D_x^* = 107.39; \quad \sigma_x^* = 10.36; \quad \chi^2 \approx 7.05$$

A hypothesis has been put forward about the subordination of the probability of container arrival by road transport to the terminal to Poisson's law (see Table 2.). In this case, $P(\chi^2)=0.66$ at the significance level $\alpha=0.1$, $\chi^2_{0.1}=13.362$, which means that the inequality $\chi^2_{0.1} > \chi^2$ is fulfilled and the hypothesis of the distribution of Poisson's law can be taken.

Simultaneously with the observation of the arrival of containers at the terminal, it is necessary to consider the time distribution for servicing container flows.

2.2 Results of servicing vehicles when unloading containers

To determine the duration of the container servicing, time-based observations of the unloading process were carried out using a gantry crane (Figure 3), as well as a reach stacker (Figure 2). The figures show the results of observation with and without combining operations.

Figure 2 shows the results of timing observation of the unloading of containers at the terminal adjacent to the station "T." The given timing was made when the gantry crane was operating at the minimum distance between the vehicle and the stacking place.
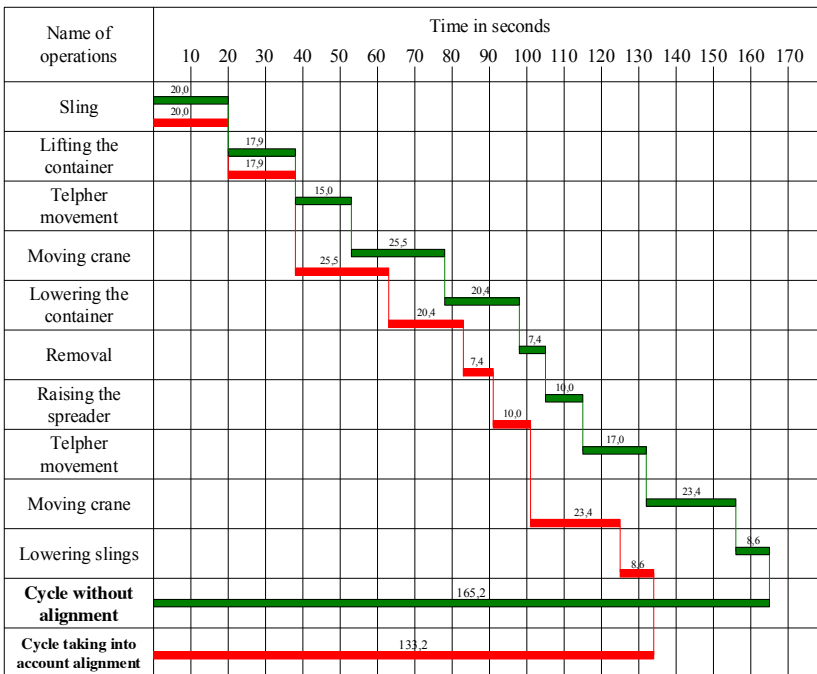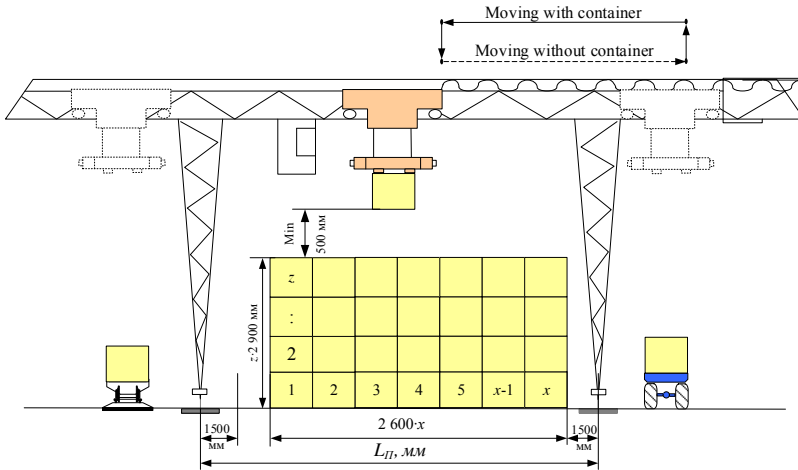
Fig.2. Working cycle of gantry crane

Based on the collection and processing of statistical data, the values of the average service time of one container were determined:

$$\tau = \sum_{i=1}^{k} \overline{\tau_i} p_i^*$$ (6)

where: $\overline{\tau_i}$ is average service value of a random variable in the i-th bit.

Table 2 shows the data on determining the probability distribution of the service time of vehicles when using a gantry crane at the terminal adjacent to the station "T".

Table 3. Distribution of probabilities of service time of vehicles by a gantry crane (fragment of the Table)

Service time τ	Observed frequency h_i	Statistical frequency p_i^*	Mathematical expectation $p_i^* \cdot \overline{\tau_i}$	Theoretical frequency p_i	χ^2
0-170	485	0.3680	31.280	0.3791	0.4500
170-340	350	0.2656	67.728	0.2354	4.8906
340-510	170	0.1290	54.825	0.1462	2.7409
510-680	118	0.0896	53.312	0.0908	0.0333
680-850	72	0.0547	41.845	0.0564	0.1200
850-1020	44	0.0334	31.229	0.0350	0.1914
1020-1190	32	0.0243	26.851	0.0218	0.3103
1190-1360	24	0.0183	23.332	0.0135	2.0000
1360-1530	15	0.0114	16.473	0.0084	0.7500
1530-1700	8	0.0061	9.8515	0.0053	0.1428
Total	1318	1.0004	356.72	0.9919	11.629

$$R=10-2=8; \ \tau \approx 5.95 \text{ min}; \ D_x^* = 108040.26; \ \sigma_x^* = 328.69; \ \chi^2 \approx 11.63$$

A hypothesis is put forward about the subordination of the probability of servicing containers to the exponential distribution law—moreover, $P(\chi^2)=0.13$ at the significance level $\alpha=0.1$, $\chi^2_{0.1}=13.362$. Therefore, the inequality $\chi^2_{0.1} > \chi^2$ is satisfied. The hypothesis of the distribution of the probability of servicing containers according to the exponential law can be accepted. The histogram and hypothetical density curve of the exponential distribution law are shown in Figure 3.
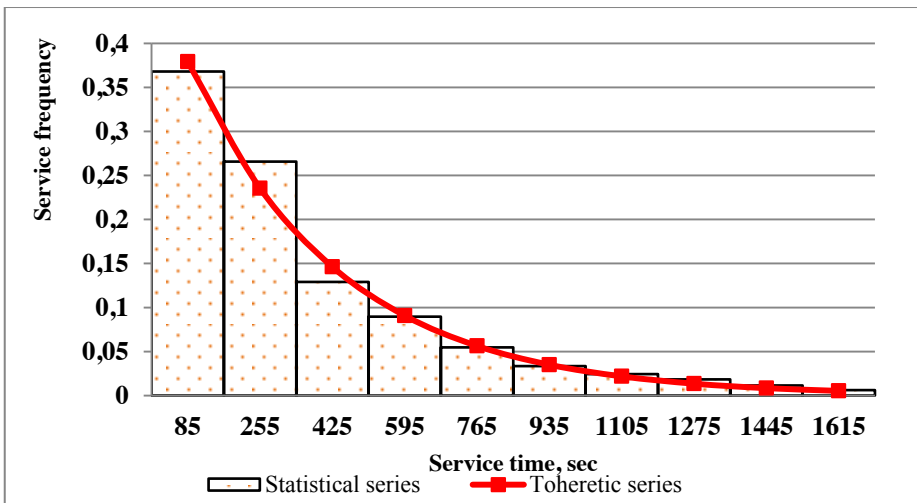
Fig.3. Histogram and hypothetical exponential distribution density curve at τ=357 sec.

Knowing the average values of λ and τ, it is possible to determine the values of the main indicators of the system under study.

3 Results and Discussion

The quality of functioning of container terminals can be assessed by several indicators, the choice of which depends on the nature of the object's task. The main indicators and their relationship between them are shown in Table. 4.

Table 4. Main performance indicators of the container terminal adjacent to station "T" (in z=2 pcs., T=8 hour.)

№	Indicators	Formula	Indicator values
1	System load	$\rho = \dfrac{\lambda}{\mu}$	600
2	Average waiting time for service	$\overline{\omega} = \left(\dfrac{\overline{\tau}}{T}\right)^2 \cdot \dfrac{N}{z\left(1 - \dfrac{N \cdot \tau}{z \cdot T}\right)}$	0.02
3	Average queue length	$\overline{v} = \lambda\overline{\omega}$	1.92
4	Average residence time of requirements in the system	$\overline{u} = \overline{\tau} + \overline{\omega}$	5.97
5	Average number of requests	$L = \lambda\overline{u}$	573

where: z is number of lifting and transport vehicles; μ is service intensity: $\mu = \dfrac{1}{\tau}$.

Based on table 3 with the initial parameters, it is not difficult to determine the rational values of these parameters. It is also possible, if necessary, to determine the total idle time of vehicles under container unloading or the total service time of N containers awaiting service during T.

Develop a mathematical model to find the optimal operating mode of a container terminal when forming a container blocks train. When servicing block trains, the main parameters of the container terminal are highlighted, which affect the organization of the block train. These include the number of feeds of fitting wagons to the loading and unloading track x, the number of wagons in the feed m, the number of hoisting-and-transport vehicles serving the block train z, and the operating time of the container terminal T.

The problem of optimizing the parameters of a container terminal can be formulated as follows: for the given characteristics of the incoming flow of the requirement λ and the type of service system τ of the block train, it is necessary to find such values of the variable parameters x, m, z, T at which the optimization criteria would lead to a minimum:

$$R^*\left(x,m,z,T\right) = \min_{x,m,z,T} R \tag{8}$$

in this case, the following constraints must be imposed on the variables x, m, z, T:

$$\left.\begin{array}{l} x_{\min} \le x \le \dfrac{N_{sut}}{\eta \cdot m} \\[3mm] \dfrac{N_{sut} \cdot t_{sic}}{60 \cdot T} \le z \le z_{\max} \\[3mm] m_{\min} \le m \le \dfrac{L_{jd}}{l_v} \\[3mm] \dfrac{N_{per}}{z \cdot N_{hour}} \le T \le 24 \end{array}\right\} \qquad (9)$$

where N_{sut} is number of containers for shipment by block train, cont;

η is number of twenty-foot containers on the k-th fitting platform, cont;

m is number of k containers in the feed;

L_{jd} is length of railway loading and unloading track, m;

$l_в$ is length of the k-th fitting platform, m;

N_{per} is volume of cargo handling, cont.-operations per day;

N_{hour} is technical performance of hoisting-and-transport machines, cont, hour.

R_1 is logistics costs associated with the downtime of fitting wagons during cargo operations. Upon the arrival of fitting wagons to the address of the container terminal:

$$R_1 = \frac{365 \cdot n^2 \cdot S_{vag}}{x \cdot z \cdot N_{hour}} \qquad (10)$$

where: n is the number of fitting cars arriving in a container block train, wagons ;

$S_{ваг}$ is cost of 1 wagon-hour of downtime, million soums;

R_2 is logistics costs associated with the supply and cleaning of wagons at the loading and unloading track:

- when fitting cars arrive by block trains [5-7]:

$$R_2 = 365 \cdot x \cdot t_m \cdot S_l \qquad (11)$$

- if the block train is divided into x_m parts before feeding:

$$R_2 = 365 \cdot m \cdot x_m \cdot S_l \qquad (12)$$

where t_m is time for filing and cleaning, hour;

$S_л$ is cost of 1 loco-hour of shunting work, million soums;

R_3 are expenses related to wages, mln. soums:

$$R_3 = 365 \cdot T \cdot \left(z \cdot a + a_k\right) \qquad (13)$$

where: a is wages of workers servicing the hoisting-and-transport machine, referred to 1 hour of its work, million soums;

a_k is the cost of maintaining a container terminal related to 1 hour of its work, million soums);

R_4 are expenses related to the maintenance of the hoisting-and-transport vehicle, mln. soums:

$$R_4 = z \cdot K_z \cdot (\alpha + \beta) \cdot 0.01 \qquad (13)$$

where: α is annual depreciation charges for the complete restoration of the hoisting-and-transport machine;

β is the annual depreciation deductions for the repair of the hoisting-and-transport machine;

K_z is the cost of the hoisting-and-transport vehicle, million soums.

R_5 is the expenses related to the maintenance of the loading and unloading track, million soums:

-when the fitting cars arrive by block trains:

$$R_5 = m \cdot l_в \cdot K_n \cdot (\alpha + \beta) \cdot 0.01 \qquad (14)$$

- if the block train is divided into x_m parts before feeding:

$$R_5 = m \cdot x_m \cdot l_в \cdot K_n \cdot (\alpha + \beta) \cdot 0.01 \qquad (15)$$

where: α is the annual depreciation deductions for the complete restoration of loading and unloading tracks;

β is the annual depreciation deductions for the repair of loading and unloading tracks;

K_n is the cost of 1 running meter of loading and unloading track, million soums.

R_6 are costs associated with waiting for vehicles to perform loading and unloading operations:

$$R_6 = 365 \cdot \tau \cdot \lambda \cdot S_m \qquad (16)$$

where: S_m is cost of 1 hour of vehicle downtime, million soums. As part of the study, an algorithm has been developed for finding the optimal operating mode of a container terminal when forming a container block train. Figure: 4. Algorithm for finding the optimal operating mode of the container terminal. The figure shows the dependence of the logistics costs of the container terminal adjacent to the station "T" for the following parameter values $m =14$ car/und; $z =2$ (gantry crane), pcs; $T=8$ hours.
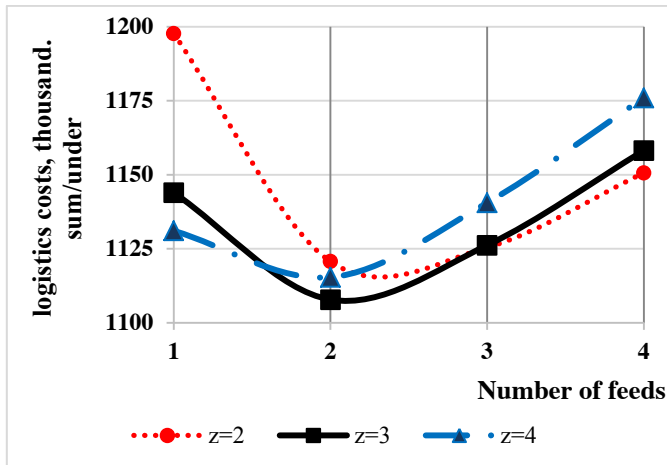
Fig.5. Dependence of logistics costs of a container terminal when using gantry cranes
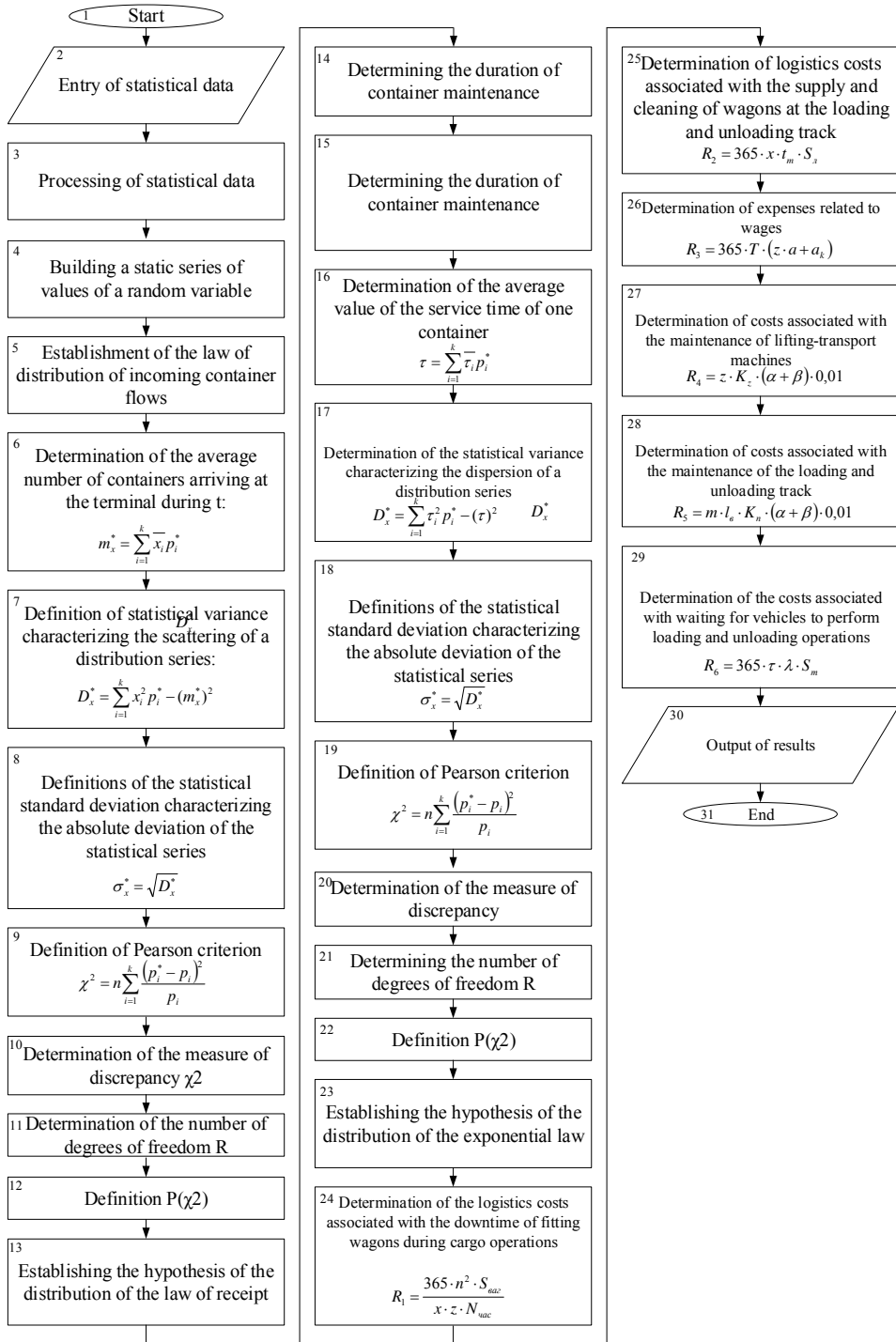
Fig.6. it can be seen that by changing the number of feeds, the optimal operating mode of the container terminal was determined when forming a container block train.

4 Conclusions

Based on the research carried out, the following conclusions can be drawn:

1. The nature of the receipt of containers at the terminal by road has been determined. In most cases, the distribution obeys Poisson's law.

2. As a result of processing the statistical data of container unloading observations, it has been established that the service duration obeys the exponential distribution law.

3. The main values of the indicators of the container terminal have been determined. In the future, to improve or search for rational values of indicators, you can change the set parameters.

4. A mathematical model and an algorithm for finding the optimal operating mode of a container terminal for organizing a container block train have been developed.

5. The results of modeling the operation of the container terminal showed that a change in feed affects the logistics costs of organizing block trains.

Reference

1. Voynov K. *Stability of the laws for the distribution of the cumulative failures in railway transport*, Transport problems, **3**. (1). pp. 35-40. (2008)

2. Bakirov A.R. *Investigation of operating modes of rolling stock by statistical methods*, Science and technology of transport, (1). pp. 82-89. (2007).

3. Bakirov A.R. *Research of operating modes of rolling stock by methods of the theory of probabilities and mathematical statistics,* Transport of the Urals, **4** (15). pp. 20-24. (2007).

4. Bakirov A.R. *Research of operating modes of rolling stock by methods of the theory of probabilities and mathematical statistics*, Bulletin of the Moscow Automobile and Road Institute (State Technical University), **3** (10). pp. 27-32. (2007).

5. Ilesaliev D.I. *Determination of the optimal values of the parameters of the loading and unloading area of packaged cargo*, Bulletin of the Petersburg University of Railways, **3** (44). pp. 55-63. (2015)

6. Ilesaliev D.I. *Determination of the optimal parameters of the loading and unloading area using mathematical methods,* Transport: problems, ideas, prospects: Sat. tr. LXXV All-Russian. scientific and technical conf. students, graduate students and young scientists. - SPb .: FGBOU VPO PGUPS, pp 227-233. (2015).

7. Korovyakovsky E.K. *Regularities of transport service of cotton fiber cargo traffic*, Intelligent systems in transport: a collection of abstracts of the VI international scientific and practical conference dedicated to the 85th anniversary of the Faculty of Transportation Management. - SPb .: FGBOU VO PGUPS, pp. 47-48. (2014).

8. Kochneva D.I. *Modeling of streaming processes at a container terminal*, Bulletin of the Ural State University of Railways, **2**. (22). pp. 53-60. (2014)

9. Kudryavtsev V.A, Zhukovskiy E.M, Efimenko Yu. I., Romanov A.P, Semyonov V.M, *Application of mathematical methods in operational calculations on railway transport*, **1**.L LIIZHT p. 65. (1977).

10. Malykhin M.O. *Justification of the initial data when modeling the export of containers from the port to the rear terminal using the Block-Train technology,* M.O. Malykhin, A.V. Kirichenko, Bulletin of the State University of Marine and River Fleet named after Admiral S.O. Makarova. **4**. (32). pp. 22-30. (2015).

11. Mironyuk V.P. *Processing of the distribution of time for servicing vehicles when handling containers*, Engineering Bulletin of the Don, **4.** (18). pp. 568-572. (2011).

12. Malikov O.B *Increase in processing capacity of the container terminal*. Vestnik gosudarstvennogo morskogo universiteta im. admirala F.F. Ushakova, **3,** (8), pp. 36-41. (2014).

13. Daurenbek I. Ilesaliev, Shahboz R. Abduvakhitov,Azizbek F. Ismatullaev, Shakhobiddin G. Makhmatkulov. *Research of the main storage area of the container terminal*. International Journal of Engineering and Advanced Technology (IJEAT), **9** (1), pp 4625-4630. (2019).

14. Ilesaliev, I.I., Makhmatkulov, S.G., Abduvakhitov, S.R. *Peculiarities of container terminal functioning in delivery chains*. IOP ConferenceSeries: Materials Science and Engineering, **918** (1), 012043. (2020).

15. D.I.Ilesaliev, Sh.R.Abduvakhitov, G.R.Ibragimova, F.K.Azimov *Razrabotka klassifikatsii konteynernykh terminalov po urovnyu razvitiya.* Transport sholkovogo puti, **3**, (2020)

16. Luo J, Wu Y, Halldorsson A, Song X, *Storage and stacking logistics problems in container terminals*. OR Insight (24): pp 256–275. (2011)

17. Stahlbock, R. and Voss, S. *Operations research at container terminals*: a literature update. OR Spectrum, **30** (1) pp 1–52. (2008).

18. Steenken D, Voß S, Stahlbock R, *Container terminal operations and operations research - a classification and literature review*. OR Spectrum **26**: pp 3–49. (2004).

19. Chen, L., Lu Z. *The storage location assignment problem for outbound containers in a maritime terminal,* International Journal of Production Economics, **135**, pp 73–80, (2012)

20. Cristina Serban, Doina Carp *A Genetic Algorithm for Solving a Container Storage Problem Using a Residence Time Strategy.* Studies in Informatics and Control, **26**, (1), March 2017. (2017).

21. Dekker R, Voogd P, Van Asperen E. Advanced methods for container stacking. OR Spectrum 2006; **28** (4), 563—86. (2006)

22. Galle, V., Barnhart, C., and Jaillet, P. A new binary formulation of the restricted container relocation problem based on a binary encoding of configurations. European Journal of Operational Research, **267** pp 467–477. (2018).

23. Khadjimukhametova M.A., Merganov A.M. *Method for calculating the injection effect to create air circulation inside containers.* International Journal of Innovative Technology and Exploring Engineering, **9** (1), 3222-3224. doi:10.35940/ijitee.A9160.119119. (2019).

24. Ilesaliev, D., & Avaz, M. *Research package efficiency general cargo*. International Journal of Engineering and Advanced Technology, **9** (1), pp 6880-6884. doi:10.35940/ijeat.A2992.109119. (2019).