Peculiarities of container terminal functioning in delivery chains

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Abstract. The purpose of this article is to study the container terminal as a complex technical system. The object of study is a container terminal. The subject of the study is a functional study of the container terminal at the junction of road and rail transport. The research methodology is based on the Markov random processes scheme. An example of a method for determining the number of reach players is given.

1. Introduction
The study of the container terminal in the delivery chain involves several stages and should contain a gradual complication of the approach, so that each subsequent method incorporates the results of research on all previous methods and solves new problems.

The first stage in the system approach is a comprehensive and meaningful description of the system, which goes in parallel with the development of terminology and the recording of existing or unknown concepts. Conceptual apparatus formation of the construction process and functioning of container pick&place system in delivery chains is the basis for its further formalization.

To represent the pick&place process as a system object, you must first select the elements of which it consists, and the structure, i.e., the interrelation of these elements. This is done at the structural research stage.

The system approach at functional research studies the interrelation of elements characterizing their values in the pick&place process of work on the basis of abstract mathematical models. When constructing a system of container pick&place process in the delivery chains as a whole or for individual subsystems, the previously identified statistical relationship is used.

In the conditions of continuous growth of container flow on the railways of Uzbekistan, a significant problem is the increase in the capacity of container terminals. This problem is related not only to the rational design or reconstruction of the terminal, but also to the increased use of loading and unloading machines, container placement and throughout capacity.

In the present study, it is proposed to solve the issue of site capacity by studying the relationship between the main parameters of the container terminal, transport package (container) and straddle carrier.

2. Review of References
In modern society, systemic ideas have already reached such a level that the idea of usefulness of a systemic approach to solving many problems is generally accepted. For the first time the study of...
logistics complexes (covered warehouse, cargo yard, container terminal, etc.) as a system object was proposed by Professor O.B. Malikov [1].

In foreign resources of literature, the study of the cargo terminal capacity is also connected with the participation of water transport. In [2] the issue of container placement is considered, the first stage is to determine the approximate number of container seats in each tier. More precise container capacity is determined at the second stage. The question of placement at the first stage is solved by means of linear programming, while at the second stage transposition of containers is applied. As noted in [3] one of the strategies for managing container capacity in a terminal is the storage life, and each incoming container is assigned to a priority class. The authors of the study [4] considered the issue of container stacking at an automated container freight terminal. This work analyzes variants of placing the containers in accord with the categories offered in article. The article [5] is related with the search of rational container placement, which minimizes the number of loading and unloading operations required for transshipment from marine to road transport. The authors Kim K.H. (Kim K.H.) and Kim H.B. (Kim H.B.) have developed mathematical models and methods to obtain an optimal solution for capacity utilization. It was suggested that newly arrived containers should not be stacked on containers that arrived earlier [6]. The research [7-9] notes that over the last four decades the interest in the study of container terminal operations has increased. For example, the article "Storage and stacking logistics problems in container terminals" analyzes and classifies the sources of literature on finding a solution to the problems of storage and placement of containers in the terminal [7]. Authors of [8] set a goal to inform the scientific community in the field of capacity and functioning of the container terminal. The article [9] describes and classifies the main logistics processes and operations in container terminals and provides an overview of their optimization methods. The authors of the article [10] considered the issue of optimization of loading and unloading machines in the placement and removal of containers from the terminal storage area. In [11] the movement of a loading and unloading machine in the main container terminal storage area was investigated.

The above literature does not have a uniform approach to determine the capacity of the container terminal, and researches are often focused on the problem of interaction of water transport with land transport modes.

3. Methodology of container terminal operation

In the process of interaction in the delivery chains in terms of arrival and departure of different modes of transport, container terminals move from one condition to another. Changes are dependent on the execution of different operations, the beginning and the end of which depend on the arrival and departure of the transport.

A probabilistic model of this phenomenon can be used to calculate the value of the parameters that characterize the efficiency of this operation. To describe such operations, a mathematical apparatus, the so-called "Markov Random Processes", can be successfully applied.

In accordance with the theory of Markov random processes, the terminals under study are considered as a complex technical and economic system. As it is known, \( X=\{x_i\}, \ i=1,n \) is a finite set and has many edges \( E=\{e_{ij}\}, i,j=1,n \)

The main vertices of the graph of terminals’ operation state in CPU looks like:
\( x_1 \) - railway loading/unloading section;
\( x_2 \) - temporary storage area for containers;
\( x_3 \) - automobile loading/unloading section;
\( x_4 \) - main storage area.

Transitions from one state to another are described as follows:
\( e_{12} \) - unloading of containers from the fitting platform into the temporary storage area;
\( e_{13} \) - direct transshipment of containers from rail to road transport;
\( e_{14} \) - unloading of containers from railway rolling stock into the main storage area bypassing the temporary storage area;
\( e_{21} \) - loading of containers from the temporary storage area into the railway rolling stock;
e23 - loading of containers from the temporary storage area onto road transport;
e24 - movement of containers from the temporary storage area to the main storage area;
e31 - direct transshipment of containers from road to rail transport;
e32 - unloading of containers from road transport into the temporary storage area;
e34 - unloading of containers from road transport into the main storage area, bypassing the temporary storage area;
e41 - loading of containers from the main storage area into the railway rolling stock;
e42 - movement of containers from the main storage area to the temporary storage area;
e43 - loading of containers from the main storage area onto the road transport;

Figure 1 shows the resulting graph of terminals’ statuses.

Figure 1. Graph of terminals’ statuses.

The adjacent matrix in formula (1) allows to store the graph of terminals’ statuses, as well as perform operations with it.

\[
A = \begin{bmatrix}
e_{11} & e_{12} & e_{13} & e_{14} \\
e_{21} & e_{22} & e_{23} & e_{24} \\
e_{31} & e_{32} & e_{33} & e_{34} \\
e_{41} & e_{42} & e_{43} & e_{44}
\end{bmatrix}
= \begin{bmatrix}
0 & 1 & 1 & 1 \\
1 & 0 & 1 & 1 \\
1 & 1 & 0 & 1 \\
1 & 1 & 1 & 0
\end{bmatrix}
\] 

(1)

In the course of terminal operation, under the influence of arrival and departure transport, this system passes from one state to another. The conditions are characterized by a greater or lesser number of technological operations.

Terminal operation is a complex process which is associated with transitions dependent on container flow.

4. Terminal status model during discrete time

Mathematical description methods of the Markov random process of the terminal with discrete statuses, depend on the moments of time the transitions occur.

A random process is called a process with discrete time - if the transition from one state to another is possible only at a strictly defined time: \( t_1, t_2, \ldots \). In the intervals between moments, the S system retains its state. Knowing the statistics of arrival and departure of transport to the terminal, it is possible to determine the average time of the logistics object in one or another state.

In accordance with the theory of Markov random processes, the terminals under study will be considered as a physical system S with discrete states \( S_1, S_2, \ldots S_n \), and the transitions of the system from state to state are possible only at moments: \( t_1, t_2, \ldots t_k \). The random process that occurs on terminals is that at successive points in time, the system behaves as follows:

\[ S_1 \rightarrow S_2, \rightarrow S_4 \rightarrow S_1 \ldots \] 

(2)

Or, at times, the system may remain the same:

\[ S_1 \rightarrow S_1 \rightarrow S_2, \rightarrow S_3 \rightarrow S_4 \rightarrow S_1 \] 

(3)
Knowing the daily statistics of arrival and departure of transport, it is possible to determine the average time of the terminal in one or another state, as well as to calculate the probabilities of states of $P_i(k)$ after the $k$-step transition:

$$P_i(k) = \sum_{j=1}^{n} P_j(k-1)P_{ji}(i=1,...,n) \quad (4)$$

where $P_j(k-1)$- the probability of the system being in $S_i$ state, at the previous discrete moment of time ($k-1$).

Probabilities of system transitions can be recorded in the form of a matrix of probability transitions:

$$P_{ij} = \begin{bmatrix}
P_{11} & P_{12} & P_{13} & P_{14} \\
P_{21} & P_{22} & P_{23} & P_{24} \\
P_{31} & P_{32} & P_{33} & P_{34} \\
P_{41} & P_{42} & P_{43} & P_{44}
\end{bmatrix} \quad (5)$$

Figure 2 shows the graph of terminal status for the Markov Discrete Time Circuit.

The Markov circuit equations of discrete time for the system can be recorded in a form:

$$\begin{cases}
P_1(k) = P_{11}(k-1)P_{11} + P_{12}(k-1)P_{21} + P_{13}(k-1)P_{31} + P_{14}(k-1)P_{41}; \\
P_2(k) = P_{11}(k-1)P_{12} + P_{22}(k-1)P_{22} + P_{32}(k-1)P_{32} + P_{42}(k-1)P_{42}; \\
P_3(k) = P_{11}(k-1)P_{13} + P_{23}(k-1)P_{23} + P_{33}(k-1)P_{33} + P_{43}(k-1)P_{43}; \\
P_4(k) = P_{11}(k-1)P_{14} + P_{24}(k-1)P_{24} + P_{34}(k-1)P_{34} + P_{44}(k-1)P_{44};
\end{cases} \quad (6)$$

The system of equations of the Markov discrete time circuit describes the process of terminal work transition from one condition to another.

5. Terminal status model in the process of continuous time

In production, the most common situations are when the system transitions from state to state occur at random time. This is due to the uneven arrival and departure of rail and road transport. The Markov Random Process with Continuous Time scheme is used to describe such processes.

The probability of $P_i(t)$ that at time $t$ the container terminal system is in the state $S_1, S_2...S_n$, forms a complete group.

In the case of continuous time, the probability of terminal system transition is the density of the transition probability. The density of the transition probability $\lambda_{ij}$ is the limit of the ratio of the transition probability for the time $\Delta t$ from the state $S_i$ to the state $S_j$ to the length of the interval $\Delta t$:

$$\lambda_{ij} = \lim_{\Delta t \to 0} \frac{P_{ij}(\Delta t)}{\Delta t} \quad (7)$$

where $P_{ij}(\Delta t)$ is the probability that the terminal system, which was in the $S_i$ state at the moment $t$, will pass from it to the state $S_j$ during the time $\Delta t$.

Figure 3 shows the graph of the terminal system statuses. Knowing the marked graph of statuses, it is possible to determine the probabilities of system statuses as a function of time:
Probabilities satisfy a differential equation of a certain kind called the Kolmogorov equation:

\[
\begin{align*}
\frac{dP_1(t)}{dt} &= \lambda_{12}P_1(t) - \lambda_{13}P_1(t) - \lambda_{14}P_1(t) + \lambda_{21}P_2(t) + \lambda_{31}P_3(t) + \lambda_{41}P_4(t) = \\
&= -P_1(t)(\lambda_{12} + \lambda_{13} + \lambda_{14}) + \lambda_{21}P_2(t) + \lambda_{31}P_3(t) + \lambda_{41}P_4(t); \\
\frac{dP_2(t)}{dt} &= \lambda_{21}P_2(t) - \lambda_{23}P_2(t) - \lambda_{24}P_2(t) + \lambda_{12}P_1(t) + \lambda_{32}P_3(t) + \lambda_{42}P_4(t) = \\
&= -P_2(t)(\lambda_{21} + \lambda_{23} + \lambda_{24}) + \lambda_{12}P_1(t) + \lambda_{32}P_3(t) + \lambda_{42}P_4(t); \\
\frac{dP_3(t)}{dt} &= \lambda_{31}P_3(t) - \lambda_{32}P_3(t) - \lambda_{34}P_3(t) + \lambda_{13}P_1(t) + \lambda_{23}P_2(t) + \lambda_{43}P_4(t) = \\
&= -P_3(t)(\lambda_{31} + \lambda_{32} + \lambda_{34}) + \lambda_{13}P_1(t) + \lambda_{23}P_2(t) + \lambda_{43}P_4(t); \\
\frac{dP_4(t)}{dt} &= \lambda_{41}P_4(t) - \lambda_{42}P_4(t) - \lambda_{43}P_4(t) + \lambda_{14}P_1(t) + \lambda_{24}P_2(t) + \lambda_{34}P_3(t) = \\
&= -P_4(t)(\lambda_{41} + \lambda_{42} + \lambda_{43}) + \lambda_{14}P_1(t) + \lambda_{24}P_2(t) + \lambda_{34}P_3(t);
\end{align*}
\]

When compiling this system of differential equations, it can be written as:

\[
\frac{dP_i(t)}{dt} = -\sum_{j=0}^{n} \lambda_{ij}P_j(t) + \sum_{j=0}^{n} \lambda_{ji}P_i(t)
\]

(10)

The system of equations (9) describes the dynamics of the probability of finding the terminal in one of the conditions.

6. Method applications for determining the number of reach stackers

An example of the use of the terminal status model over the time is that the probability of each possible site state is taken into account, and the total number of reach stackers is determined on the basis of requirements for each of these sites, per the formula:

\[
r = \sum_{i=1}^{n} r_i \cdot P_i
\]

(11)

where \( r_i \) is the number of reach-stackers required for the \( i \) status of the terminal sites;

\( P_i \) - the probability that the terminal will be in the \( i \) status;

\( n \) - number of terminal statuses.

Terminal statuses are a complete group of events:

\[
\sum_{i=1}^{n} P_i = 1.00
\]

The number of reach-stackers required to perform a separate loading/unloading operation can be determined as follows:

\[
r_j = \frac{Q_j}{q_j}
\]

(12)
where \( Q_j \) is the required performance of \( j \)-th container flow, cont/h;
\( q_j \) - performance of one reach-stacker on the \( j \)-th container flow, cont/h.

As a result of monitoring and data processing, the terminal performance indicators are set forth in Table 1. The total duration of the terminal simulation:
Total = 180 days - 1 working shift - 8 hours of operation = 1440 hours

Table 1. Baseline data.

| № | Description of status | Time of being in the condition \( T, \) h | Required capacity of container flow \( Q_j, \) t/h (interterminal) | Probability Of Condition \( P_i = T_i / T \) |
|---|------------------------|------------------------------------------|-------------------------------------------------|----------------------------------|
| 1 | There's no work for a reach-stacker | 153 | 0 0 0 | 0.11 |
| 2 | Unloading of containers from the platform to the terminal | 210 | 200 0 0 | 0.15 |
| 3 | Loading containers from the terminal to the platform | 251 | 0 0 100 | 0.18 |
| 4 | Unloading of platforms, direct transshipment into vehicles | 209 | 120 40 60 | 0.15 |
| 5 | Unloading of vehicles, direct transhipment to the platform | 201 | 80 20 40 | 0.14 |
| 6 | Moving of containers from the temporary storage area to the main storage area | 186 | 0 40 60 | 0.13 |
| 7 | Moving of containers from the main storage area to the temporary storage area | 190 | 0 80 40 | 0.14 |
| Total | | 1440 | - - - | 1.00 |

Designations of interterminal cargo flows in table 1 and 2:
1-unloading from wagons to transshipment warehouse;
2-direct transshipment;
3-loading from the transshipment warehouse to vehicles.

Table 2. Calculations of the required number of reachstackers for container processing.

| № conditions \( i \) | The probability of condition \( P_i \) | The required number of reach-stackers | The total number of reach stackers the \( i \)-th condition at the site \( r_j \) | \( r_j \cdot P_i \) |
|----------------------|----------------------------------------|---------------------------------------|------------------------------------------|----------------|
| 1                    | 2                                     | 3 4 5                                 | 6                                       | 7              |
| 1                    | 0.11                                   | 0 0 0                                 | 0                                       | 0              |
| 2                    | 0.15                                   | 5.29 0 0                             | 5.29                                    | 0.79           |
| 3                    | 0.18                                   | 0 0 2.64                              | 2.64                                    | 0.47           |
| 4                    | 0.15                                   | 3.17 1.05 1.58                        | 5.8                                     | 0.87           |
| 5                    | 0.14                                   | 2.11 0.53 1.05                       | 3.69                                    | 0.51           |
| 6                    | 0.13                                   | 0 1.05 1.58                          | 2.63                                    | 0.34           |
| 7                    | 0.14                                   | 0 2.11 1.05                          | 3.16                                    | 0.44           |
| Total                | 1.00                                   | - - -                                 | -                                       | 3.42           |
Rich stacker performance is 20 cont/hour at average. Based on the results of calculations in Table 2, the total number of reach stackers for the terminal can be assumed \( r = 4 \), as the total number of reach stackers acceptable for all statuses of the terminal sites.

7. Conclusion
Condition models based on the Markov circuits to describe the terminal operation allow to assess the loading and unloading areas for road and rail transport, as well as for temporary and main storage areas in the process of discrete and continuous time.

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