Development of mathematical models of the relationship between the main parameters of a container depot

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Abstract. The purpose of the article is to develop a method for reliably determining the most rational values of container depot parameters, thereby improving and increasing the level of customer service for transport in general. Research methods are based on a system analysis and generalization of existing methods and methods for calculating the capacity of container terminals. The results of the study are the technique of determining the capacity of the warehouses in railway transport, ensuring more qualified calculation and selection of parameters of the container depot, as well as reducing erroneous design decisions and improving the reliability of development projects and improvement of the transport network as a whole.

1. Introduction

Today, there is a trend of development of container transportation all over the world, but this can not be said about the level of containerization in Uzbekistan. This is mostly due to the shortage of containers in the freight transport market, as well as the lack of logistics facilities, and a small share of transit traffic.

For example, the park of containers of the country's main operator, Uztemiryulcontainer JSC, is less than 1000 units in twenty-foot equivalent (TEU). In this regard, the task is to solve this problem by organizing a container depot, which will increase the level of customer service for railway transport and the transport network as a whole.

2. The description of the object

Modern cargo terminal complexes are complex technical objects. In this study, a system analysis of a technical object is used as the main methodology for studying a container depot. According to which any object under study can be considered as a system that has certain elements (technological sections of a container depot), the relationship between elements (information and container flows), and are united by a common goal of functioning (rational transformation of container flow parameters).

The structure of a container depot in accordance with the main provisions of the system analysis is a variety of relationships between the main elements: technological sections and loading and unloading machines. Figure 1 shows the technological structure of a container depot. A container depot, unlike a container terminal, consists of only three elements: an area for storing empty containers, and a railway and automobile loading and unloading area (LUA). Because of this, the container depot has a simpler structure.
The task of parametric description of container depots is reduced to their meaningful description, mathematical expression, and output of formulas for their calculation. To describe a container depot, we use its representations as a set of interrelated elements and take into account their parameters.

![Diagram of a container depot by elements: a – empty container storage area; b – automobile LUA; c – railway LUA](image)

**Figure 1.** Diagram of a container depot by elements: a – empty container storage area; b – automobile LUA; c – railway LUA

Designations in figure 1: 1 – administrative and household complex; 2 – repair shop; 3 – parking for cars and more heavy vehicles; 4 – checkpoint; 5 – railway loading and unloading area; 6 – exhibition way; 7 – two-lane roadway; 8 – stack of empty containers; 9 – loading and unloading machine.

Consequently, the total number of initial and calculated parameters of a container depot, as well as their mutual influence on each other, is quite large, which also confirms the complexity of the warehouse structure as a system object. Correctly calculated capacity will allow you to determine with greater accuracy all other parameters necessary to improve the functioning of the container depot.

3. **Comparative analysis of the main parameters of loading and unloading machines**

The advantage of forklift trucks compared to the traditional use of gantry cranes is the following: simplicity and short time to enter the container depot, the absence of crane tracks, the ability to stack containers above three tiers, etc. All these advantages have become crucial for the recommendation of these types of loading and unloading machines in a container depot. Types of loading and unloading machines are related to the layout of the general plan of the container depot and depend on the type of containers being processed. Figure 2 show the types of container loaders designed for processing and stacking various types of containers.

The most widespread in Western container terminals are forklifts with an extendable crane boom (reach stacker) (see figure 2, a). A container forklift with a side spreader grip (double stacker) has the ability to stack two empty containers at once (figure 2, b). In this regard, the technical performance of this loading and unloading machine is approximately twice as high as that of other types of forklifts. Container forklifts with top spreader grip are also used at Western terminals (see figure 2, b). The container forklift with a fork grip is a universal loading and unloading machine (see figure 2, d). Special load-handling devices for forklift trucks are allowed to perform loading and unloading operations directly and inside the container. The table 1 shows the main parameters of individual models of container loaders.
Figure 2. Container forklifts: a – reach stacker; b – double stacker; c – forklift with top spreader grip; d – with fork grip.

Table 1. Characteristics of container handling trucks

| Parameters                                      | Types of container forklifts |
|------------------------------------------------|------------------------------|
|                                                 | Reach stacker DRG100-54S     |
|                                                 | Double reach stacker DCG 100|
|                                                 | with top spreader grip DCF4  |
|                                                 | with fork grip DCF370         |
|                                                 | ED                           |
|                                                 | 100-45 ED                    |
|                                                 | 410CSG                       |
|                                                 | 370-12                       |
| Lifting capacity, in container row, t           | 10.0                         |
| 1 row                                          | 22.0                         |
| 2 row                                          | 8.0                          |
| 3 row                                          | 4.5                          |
| Stacking height, no. of containers              | 8                            |
| Container 8’6”                                 | 9                            |
| Container 9’6”                                 | 5                            |
| Aisle width, with 20 ft – 40 ft container       | 11200                        |
| Container 20 ft                                 | 14200                        |
| Container 40 ft                                 | 10846                        |
| Service weight, standard truck, kgs             | 40300                        |
| Lifting speed, m/s                              | 0.50                         |
| Unloaded                                       | 0.65                         |
| At rated load                                  | 0.42                         |
| Lowering speed, m/s                             | 0.25                         |
| Unloaded                                       | 0.42                         |
| At rated load                                  | 0.25                         |
| Travelling speed, forward – reverse, unloaded –| 8.3/8.3                      |
| at rated load, m/s                              | 6.9/6.9                      |
| speed / forward                                 | 7.2/7.2                      |
| Unloaded / At rated load                        | 7.2/7.2                      |
|                                                 | 8.3/8.3                      |
|                                                 | 6.9/6.9                      |
|                                                 | 6.4/6.4                      |
|                                                 | 6.6/6.6                      |

* – number of tiers for stacking empty containers

Taking into account the parameters of container loaders will allow a more qualified calculation.
4. Development of mathematical models of relationships between container depot parameters

The following are mathematical models that show the dependencies between individual parameters of a container depot. The total capacity of a container depot is determined by the formula:

\[ R_i = x \cdot y \cdot z \rightarrow \max \]  \hfill (1)

where \( x \) – the number of empty containers across the width of the storage area, cont; \( y \) – number of empty containers along the length of the storage area, cont; \( z \) – the number of stacking of empty containers in height.

To begin with, the useful width of the container depot is determined (the width of the technological area for storing empty containers):

\[ B_x = B - B_1 - B_2 - B_3, \text{ m} \]  \hfill (2)

where \( B \) – width of the container depot, m; \( B_1 \) – part container depot allotted for railway loading-unloading station and also the exhibition path, m; \( B_2 \) – part container depot allotted for two-lane roadway, m; \( B_3 \) – width of lawns along the fence, m.

The number of containers to be placed by width \( x \) of the empty container storage area:

\[ x = e \left( \frac{B_x - n_2 \cdot A}{b + \omega} \right), \text{ cont.} \]  \hfill (3)

where \( e\{...\} \) – the designation of the integer part, rounded down; \( n_2 \) – number of longitudinal passages, which depends on the number of containers installed at a depth of stacks \( x_1 \); \( A \) is the width of the passage for the loading and unloading machine, m; \( b \) is the width of the container, m; \( \omega \) is the technological gap between containers, located along the width of the storage area, m.

\[ n_2 = e \left( \frac{B_x - (b + \omega) \cdot x_1 - A}{2 \cdot (b + \omega) \cdot x_1 + A} \right) + 1, \text{ passage} \]  \hfill (4)

where 1 is the longitudinal passage along the railway track.

\[ L_x = L - L_1 - L_2 - L_3, \text{ m} \]  \hfill (5)

where \( L \) is the length of a container depot, m; \( L_1 \) – the length of the storage area empty containers, m; \( L_1 \) – length part of the container depot, occupied by cross passages for vehicles, m; \( L_2 \) – length part of the container depot, occupied office building, repairing shop, m; \( L_3 \) is the width of the lawn along the fence, m;

The number of containers placed along the length \( y \) of the storage area is determined as follows:

\[ y = e \left( \frac{L_x - n_1 \cdot A}{l + \lambda} \right), \text{ cont.} \]  \hfill (6)

where \( \lambda \) is the technological gap between containers located along the length of the storage area, m; \( l \) is the length of the container, m;

The number of cross passages \( n_1 \) is calculated as follows:

\[ n_1 = e \left( \frac{L_x}{80} \right), \text{ passage} \]  \hfill (7)

where 80 is the approximate length through which cross passages are installed for forklifts.

The advantage of the proposed mathematical models is that they describe the relationship of the container depot parameters to each other and to the depot operation.
Based on the developed mathematical models of the relationship between parameters, calculations were made to determine the capacity of the storage area for empty containers equipped with various types of forklifts. Figures 7-10 show graphs of the capacity of container depots depending on the depth of stacking of empty containers and the length of the storage area.

Figures 3-6 show that for different values of $x_1$, the capacity of a container depot can be the same. Therefore, it is recommended to choose the lowest value $x_1$, which will ensure a high processing capacity of the depot.

5. Conclusion
In this paper, the issue of reliable determination of the most rational values of container depot parameters is considered. During the research, the following tasks were solved and the results were obtained:

- As a rational technological equipment for container depot areas, it was proposed to use container loaders.
- The study developed mathematical models that show the relationship between the parameters of a container depot, they can be used to determine and optimize the main parameters of a container depot, as well as other types of container terminals.
Using the developed mathematical models, it becomes possible to solve various problems, such as determining the capacity of container depots, based on taking into account all possible parameters of the technological storage area, containers and forklifts.

The organization of a container depot on the railway transport can solve the problem of deficit of containers.

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