ČEDOMIR IVAKOVIĆ, D.Sc.
Faculty of Transport and Traffic Engineering
Fakultet prometnih znanosti
Vukelićeva 4, Zagreb

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METHODOLOGY OF DETERMINING THE SIZE AND EXCHANGEABILITY OF CONTAINERS AT TERMINALS

METODOLOGIJA ODREĐIVANJA VELIČINA KONTEJNERA I IZMJENJIVOSTI KONTEJNERA U TERMINALU

U radu je obrađena metodologija određivanja veličine kontejnera i izmjenjivosti kontejnera u terminalu. Veličina kontejnera utječe na izmjenjivost kao i prosječno iskorištenje nosivosti i neravnomjernost pritjecanja tereta pogodnog za kontejnerski prijevoz. Ove pretpostavke određuju veličine odlagališta, dužine i širine cestovnih i željezničkih traka i manipulacije površina kao i broj i veličinu pristana za brodove. Pored ovih elemenata na statički i dinamički kapacitet terminala utječe i prekrcajna mehanizacija

1. INTRODUCTION

The use of containers in cargo transport requires economic utilization of container space, as well as their optimal stowing in the terminal at the depot center. Since the container sizes are determined according to the ISO standards, in order to determine the container terminal or depot capacity, we determine the combinations of various container sizes.

The container terminal capacity depends on the type, number and size of the containers that have to be manipulated, as well as on the number of loading - unloading manipulations per hour, or per day. These parameters determine the size of the depot, number of depot lanes, their length, number of railway tracks, road traffic routes, type and number of cargo handling equipment, as well as the total length and width of terminal lanes. In order to determine the capacity of container terminals, the sizes of containers being manipulated, the daily capacity, the size of the depots and their form, also static and dynamic capacity such as the lengths and throughput capacity of operational shore and quay, road traffic routes and railway tracks in the terminal need to be defined.

The daily terminal capacity depends directly on types and sizes of containers being handled in the terminal. While determining the dynamic capacity, it is the container exchangeability that affects the usability of the infrastructure, container-handling and transport means. Average capacity is expressed in TEU (Twenty feet Equivalent Unit) i.e. containers of different sizes converted to 20 feet.

2. DETERMINING THE CONTAINER SIZE

When converting the size and structure of containers that are to be manipulated at the terminal, the starting point is the assumption that the proportion between full and empty containers is 50:50%. In practice this proportion is adequate to the actual situation since there is always the need to return the empty containers. Regarding the container size structure the starting point is the size of the container terminal so that in middle-sized and large terminals this proportion is:

- 40% containers of 40 feet
- 40% containers of 20 feet
- 20% containers of other sizes

For smaller container terminals this proportion is:

- 20% containers of 40 feet
- 60% containers of 20 feet
- 20% containers of other sizes.

These proportions in theoretical hypotheses can also be different in favor of 20 or 40 feet containers, depending on the cargo flows and freight structure gravitating towards the terminal.

The required number of containers can be converted for the single container terminal as well as for the terminal network in a wider area (state or county) which is done by development planning for these regions. Thus, the required number of containers for a terminal is calculated, starting from the transportation volume of cargo suitable for container transport Q_k and exploitation parameters of containers manipulation. These parameters include:

- exchangeability of containers O_k
- average usability of capacity q_k
- lack of uniformity of incoming cargo suitable for container transport γ

Apart from this, parameters related to the transport of empty containers, coefficients of internal terminal transport and the near environment as well as some other parameters that can affect the number of containers can be calculated. When determining the number of containers, the starting point is the assumption that the number presents the operational fleet of the terminal marked with N_r and the inventory N_{ik} expressed in TEU.

Therefore, the operational fleet is calculated according to the formula:

$$N_{rk} = \frac{Q_k \cdot \gamma_k \cdot O_k}{q_k \cdot 313}$$

where:

- Q_k - amount of cargo suitable for container transport, in tons per year
- O_k - exchangeability of containers, average in days for internal or international transport
- q_k - average usability of 20' container capacity
- 313 - number of working days per year

The container inventory is calculated according to the formula:

$$N_{ik} = N_{rk}\left(1 + \frac{P_k}{100}\right) \text{(piece)}$$

where:

- P_k - percentage of damaged containers being repaired or written off until the purchase of new containers.

2.1. DETERMINING THE CONTAINER EXCHANGEABILITY IN THE TERMINAL

When determining the daily terminal capacity we start from the exchange i.e. turnover of containers as the work indicator in a certain period. The daily capacity consists in a sequence of time intervals that last from the beginning of one loading to the beginning of another container loading. The container as a unit during the turnover can be found in different positions depending on the traffic branch by which it is being transported and that is:

- in transport on transport carriers (wagon, semi-trailer, ship, barge etc.)
- stored at the terminal depot
- during manipulation (loading, unloading or cargo handling)
- during filling or emptying at the warehouse and
- other terminal operations.

The exchangeability of the containers is the mean time from the moment of the container loading or its reception with the cargo, till the beginning of the next loading or delivery. In road or rail traffic this means that the exchangeability is the time needed to realize a part of the manipulation cycle from the moment of loading the container till the beginning of the next loading[1].

The exchangeability time of the container can be calculated for the operational fleet of containers that are to be loaded (full containers are meant) and for the overall container fleet. The exchangeability of the full containers O_{kP} is calculated according to the formula:

$$O_{kP} = \frac{1}{24}\left[\frac{L_{kP}}{V_k} + \frac{L_{kP}}{L_{teh}} \cdot t_{teh} + 0{,}5 k_m (t_{uk} + t_{isk}) + \frac{N_{obr}}{U_r} \cdot T_{obr} + 2\frac{L_{sr}}{V_{sr}}\right] \text{(day)}$$

- L_{kP} - the path passed by a full container
- L_k - the total path in km
- V_k - commercial speed on a certain section of the container transport on a carrier expressed in km/h
- L_{teh} - mean distance between the container-handling points in km
- t_{teh} - mean time of holding the container at the container-handling point per hour
- t_{uk} - mean loading time per hour
- t_{isk} - mean unloading time per hour
- N_{obr} - the total number of processed and stowed containers in the terminal
- T_{obr} - mean time of the container being handled at the depot
- L_{sr} - average traveling path between the transport customers
- V_{sr} - average time needed to bring the container to the terminal and returning back the semi-trailers either empty or full
- U_r - container fleet operation

The total container fleet exchangeability is calculated according to the formula:

$$O_{kP} = \frac{1}{24}\left[\frac{L_k}{V_k} + \frac{L_k}{L_{teh}} \cdot t_{teh} + 0{,}5\, k_m (1 + \alpha_k) \cdot (t_{uk} + t_{isk}) + \frac{N_{obr}}{U_r} \cdot T_{obr} + 2\frac{L_{sr}}{V_{sr}}\right] \text{(day)}$$

where:

- α_k - proportion coefficient between handling of full and empty containers, and its value can range from 0-1
- k_m - local operation coefficient, presenting the number of operations with full containers and converted by

$$k_m = \frac{U_{uk} + U_{isk}}{U_r}$$

and this coefficient can have the value 2, if $U_{uk} = U_{isk} = U_r$

U_{uk}, U_{isk} - mean waiting time of the container at loading and unloading points.

This calculation is based on the assumption that the local work coefficient is k_m with the value of 0.5, which is the sum of the mean loading time U_{uk} and U_{isk}.

3. CALCULATING THE SIZE OF THE DEPOT

The stowing of containers for a temporary depot as well as storing the containers for a longer period are directly connected to the technical and technological characteristics of the terminal. Depots for temporary storage are connected with ships' quays, railway tracks and road traffic routes, that is, with the operational part of the terminal under the gantry cranes, transporter container-loading bridges and quayside cranes. Depots for container storage depend according to the areas reserved for containers and manipulation on various kinds of container-handling equipment.

The module of stowing the containers vertically depends on the applied container-handling equipment so that at the latest built terminals there is a possibility of stowing in the area under the gantry cranes up to the level of 6 containers, as at warehouses with the use of front loaders, whereas with straddle carriers of new generation the arranging level of 3-4 containers vertically is achieved. Regarding the plan stowing area, the containers can be stowed in several depot lanes that can be situated along the longitudinal axis of the traffic route or aslant in relation to the traffic route. The container stowing possibilities in side-view, and the occupied areas depending on the container-handling equipment, and the module of container plan stowing are shown in Figure 1.

The size of the depot depends on the width and length of the lanes which in turn depend on the area occupied by a container of a certain size, as well as on the number of containers that need to be put into the depot, and all this depending on the overall terminal capacity.

The width of the terminal depends on the number of depot lanes so that dimensioning assumes the container width which is 2438 mm, so that in the case of a temporary depot the area between the crane track and the first lane which is at least 900 mm, then the area between two container lanes of 700 mm is taken into account. In the case of a two-lane depot the width is 6800 mm, although this can be narrower if the area between lanes is not left free, which depends on the type of container-handling equipment and spreaders for handling containers. The past experiences in the work of many terminals show that stowing containers in 5 lines along the width is an optimum limit and that then new depots need to be formed especially in the case of long-term storage depots.

For the calculation of the length of the depot lane - L_{kt} the following formula is used:

$$L_{kt} = \frac{N_k \cdot L_k \cdot S_k \cdot \alpha \cdot t}{T_r \cdot e_k \cdot 1000}$$

where:

N_k - number of containers daily delivered to the terminal and deposited on the lane

L_k - container length in mm

S_k - coefficient of free space in the case of longitudinal stowing of containers which for a container of 20 feet is $S_k = 6055 + 300 : 6055 = 1.050$

α - coefficient of lack of uniformity in the incoming and delivery of containers

t - average staying time of containers at the terminal depots in h

T_r - working hours of the terminal during the 24 hours expressed in h (two shifts 7 hours each = 14 hours)

e_k - number of container stowing levels

This means that the length of the depot depends on the length of the crane tracks of a gantry crane, loading-unloading railway tracks, shipping quays and road traffic routes by the depots. The overall depot area occupied by containers and the necessary communications depend on the type of transport found at the terminal and the container-handling equipment. The depot area for container storage is calculated according to the formula:

$$P = P_L + P_{ko} + P_o (m^2)$$

where:

P_L - area for stowing containers of 10', 20', 30' and 40'

P_{ko} - area for communication of handling equipment

P_o - area for other terminal facilities

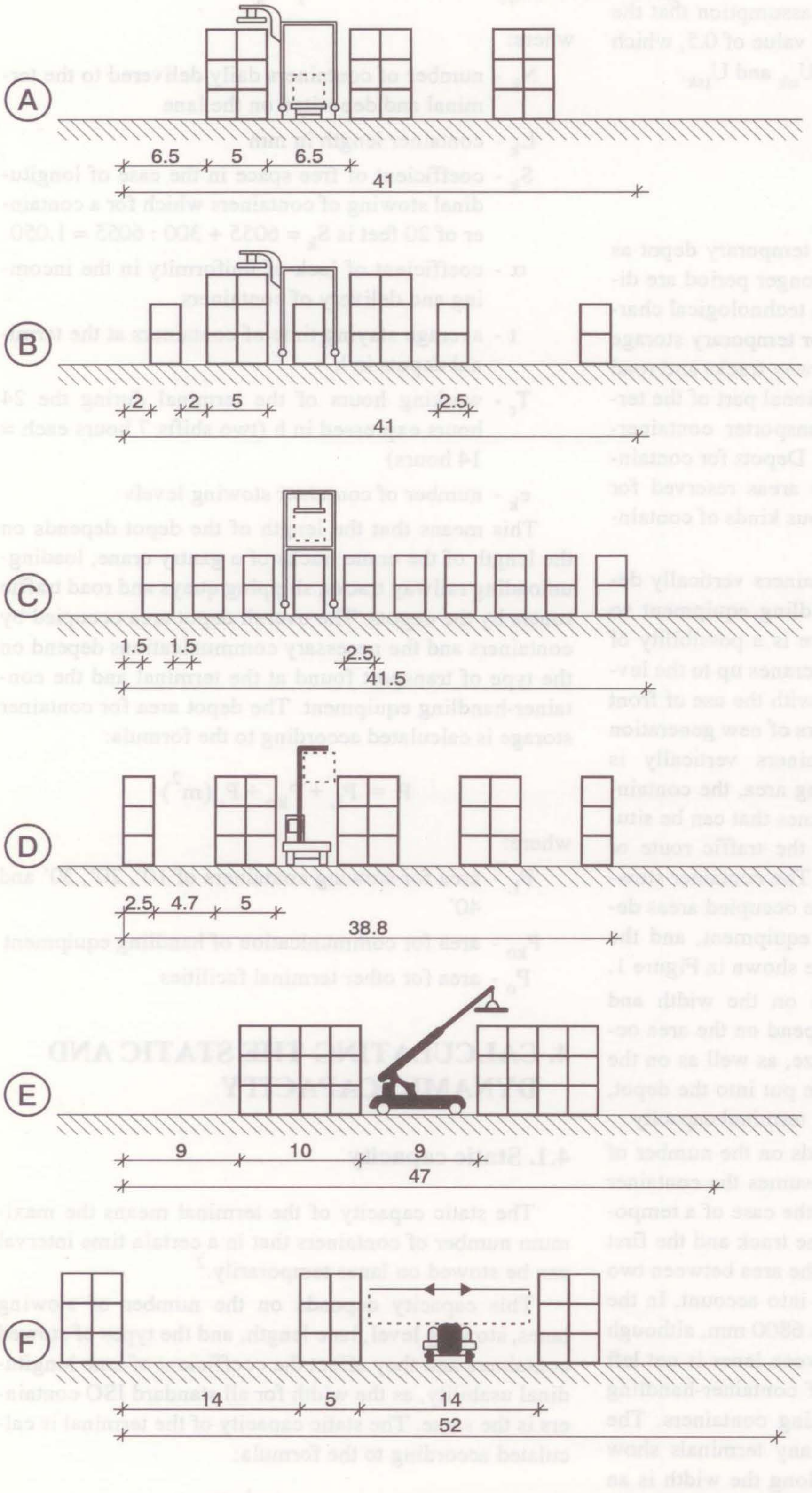
4. CALCULATING THE STATIC AND DYNAMIC CAPACITY

4.1. Static capacity

The static capacity of the terminal means the maximum number of containers that in a certain time interval can be stowed on lanes temporarily.[2]

This capacity depends on the number of stowing lanes, stowing level, lane length, and the types of stowed containers and they affect the coefficient of lane longitudinal usability, as the width for all standard ISO containers is the same. The static capacity of the terminal is calculated according to the formula:

$$N_k = \frac{n \cdot l \cdot y}{L_k}$$



length of the cross-section (m)	number of containers in the cross-section	occupied cross-section per container (m)	area per container of 40' (m²)
41	18	2,28	27,32
41	26	1,58	19
41,5	20	2,02	24,9
38,8	24	1,61	19,4
47	24	1,95	23,5
52	12	4,3	52

Figure 1 - **Modules of stowing containers - side-view**
Occupied area and dependence on the handling equipment

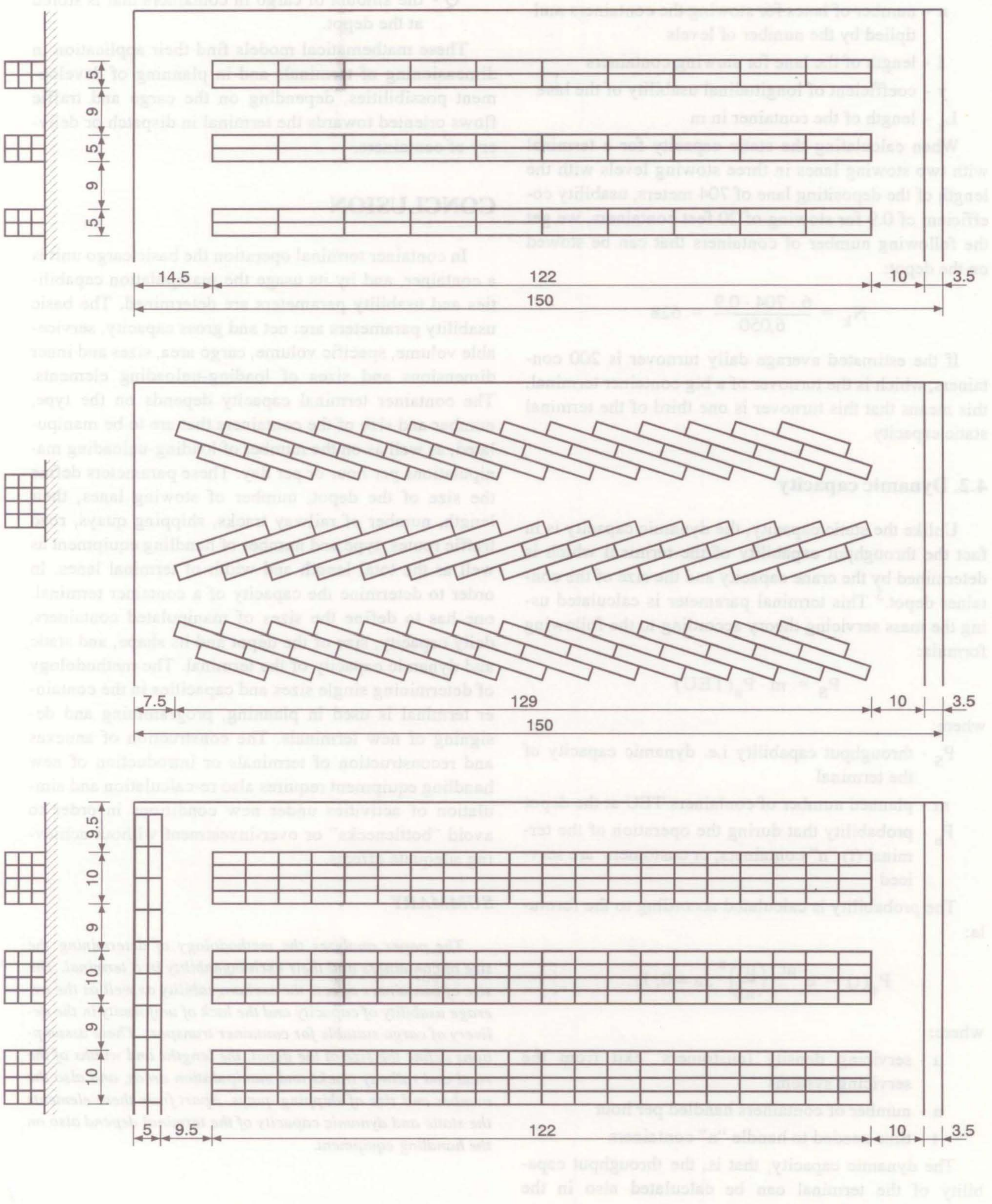


Figure 2 - **Modules of stowing containers vertically and longitudinally**

where:

N_k - number of containers that can be stowed on the temporary stowing lane

n - number of lanes for stowing the containers multiplied by the number of levels

l - length of the lane for stowing containers

y - coefficient of longitudinal usability of the lane

L_k - length of the container in m

When calculating the static capacity for a terminal with two stowing lanes in three stowing levels with the length of the depositing lane of 704 meters, usability coefficient of 0.9 for stowing of 20 feet containers, we get the following number of containers that can be stowed on the depot:

$$N_k = \frac{6 \cdot 704 \cdot 0{,}9}{6{,}050} = 628$$

If the estimated average daily turnover is 200 containers, which is the turnover of a big container terminal, this means that this turnover is one third of the terminal static capacity.

4.2. Dynamic capacity

Unlike the static capacity, the dynamic capacity is in fact the throughput capability of the terminal which is determined by the crane capacity and the size of the container depot.[3] This terminal parameter is calculated using the mass servicing theory according to the following formula:

$$P_S = m \cdot P_n(\text{TEU})$$

where:

P_S - throughput capability i.e. dynamic capacity of the terminal

m - planned number of containers TEU at the depot

P_n - probability that during the operation of the terminal (t) "n" containers, or customers are serviced

The probability is calculated according to the formula:

$$P_n(t) = e^{-\mu t} \cdot \left(\frac{\mu t}{n!}\right)^n ; n = 0, 1, ...$$

where:

μ - servicing density (customers' exit from the servicing system)

n - number of containers handled per hour

t - time needed to handle "n" containers

The dynamic capacity, that is, the throughput capability of the terminal can be calculated also in the amount of cargo handled at the terminal in a certain time period, which is determined according to the formula:

$$P_S = Q \cdot P_n \text{ (tons/year)}$$

where:

Q - the amount of cargo in containers that is stored at the depot.

These mathematical models find their application in dimensioning of terminals and in planning of development possibilities, depending on the cargo and traffic flows oriented towards the terminal in dispatch or delivery of containers.

CONCLUSION

In container terminal operation the basic cargo unit is a container, and by its usage the manipulation capabilities and usability parameters are determined. The basic usability parameters are: net and gross capacity, serviceable volume, specific volume, cargo area, sizes and inner dimensions and sizes of loading-unloading elements. The container terminal capacity depends on the type, number and size of the containers that are to be manipulated, as well as on the number of loading-unloading manipulations per hour or per day. These parameters define the size of the depot, number of stowing lanes, their length, number of railway tracks, shipping quays, road traffic routes, type and number of handling equipment as well as the total length and width of terminal lanes. In order to determine the capacity of a container terminal, one has to define the sizes of manipulated containers, daily capacity, size of the depot and its shape, and static and dynamic capacity of the terminal. The methodology of determining single sizes and capacities in the container terminal is used in planning, programming and designing of new terminals. The construction of annexes and reconstruction of terminals or introduction of new handling equipment requires also re-calculation and simulation of activities under new conditions in order to avoid "bottlenecks" or over-investment without achieving adequate effects.

SUMMARY

The paper analyzes the methodology of determining the size of containers and their exchangeability in a terminal. The size of containers affects the exchangeability as well as the average usability of capacity and the lack of uniformity in the delivery of cargo suitable for container transport. These assumptions define the size of the depot, the lengths and widths of the road and railway tracks and manipulation areas, and also the number and size of shipping quays. Apart from these elements the static and dynamic capacity of the terminal depend also on the handling equipment.

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