ВЕСТНИК
ГОСУДАРСТВЕННОГО УНИВЕРСИТЕТА
МОРСКОГО И РЕЧНОГО ФЛОТА ИМЕНИ АДМИРАЛА С. О. МАКАРОВА

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TOOL FOR ASSESSING THE RESOURCES REQUIREMENT OF A CONTAINER TERMINAL

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A simulation model of a container terminal which is used for the technological resources assessment is described in the paper. Container handling equipment and terminal area are considered as the primal resources. The main characteristics of the model include the graphical container flow model of a container terminal, which consider all container handling operations in a container terminal. Operations technology is divided into three main activities — get, move and put, which enable flexible selection of equipment type (technology). The variation of the container flow volumes and equipment productivity on each activity are considered. The study shows that the model provides more reliable assessment of container terminal resources. The simulation results are visualized by two types of graphics: the probability density of the necessary number of equipment and cumulative distribution function. Accordingly, the required terminal area is defined according to applied technology. The model configuration is based on seaports resource assessment; however, the same approach can be used for dry ports. The simulation tool can be utilized in various use cases, including monitoring terminal effectiveness and required developments against different container volume scenarios, operation strategies and comparison between different technologies. Accordingly, the tool can be utilized by consultants and equipment supplier sales representatives during early stages of port design.

Keywords: container terminal, simulation modelling, cargo handling equipment, terminal area, technology comparison, seaport, dry port, port design

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ИНСТРУМЕНТ РАСЧЕТА ПОТРЕБНОСТИ В РЕСУРСАХ КОНТЕЙНЕРНОГО ТЕРМИНАЛА

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В статье рассматривается имитационная модель контейнерного терминала, используемая для оценки количества ресурсов терминала, необходимых для обработки заданного грузопотока. Основными ресурсами подобного рода являются подъемно-транспортное оборудование и площадь контейнерного терминала. Подчеркивается, что основными свойствами описываемого в работе подхода являются графическая модель контейнерного терминала, которая позволяет учитывать все операции, осуществляемые в морском порту; разделение технологии выполнения операции на три типовых действия: «взять», «перевезти» и «положить», которые предоставляют возможность гибкой настройки технологии выполнения операций; учет вариации объемов контейнеропотоков и производительности технологического оборудования на каждой операции. Исследование, описанное в статье, показывает, что указанные свойства позволяют получить более надежные расчетные характеристики ресурсов контейнерного терминала за счет более подробной настройки расчета. Результаты расчетов представлены двумя типами графиков: плотности и интегральной функции *вероятности. Модель выполнена для расчетов характеристик ресурсов морского порта. Однако этот подход может быть использован для проведения расчетов ресурсов сухих портов. При расчете необходимого количества подъемно-транспортного оборудования учитываются характеристики контейнерного штабеля, влияющие на трудоемкость выборки контейнеров. В статье указывается, что модель может быть использована как инструмент постоянного контроля за эффективностью работы терминала и выявлением необходимых изменений. Вместе с тем она может быть использована производителями контейнерного перегрузочного оборудования как инструмент для специалистов по продвижению, которые являются главными консультантами инвесторов на первых этапах проектирования контейнерных терминалов.*

Ключевые слова: контейнерный терминал, имитационное моделирование, подъемно-транспортное оборудование, площадь терминала, сравнение технологий, морской порт, сухой порт, проектирование порта.

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Introduction

The ever-growing competition and demand for higher level of productivity and services push the container ports towards constant development [1]–[3]. Primarily opportunities and changes concern the equipment and technology that fundamentally enable terminal operations and to the great extend determine its overall efficiency.

Any terminal maintaining its competitiveness to respond growth and market-driven accommodation should permanently monitor the development of commercial and operational environment in order to take proper decisions in due time [4], [5]. The main factors in this consideration are the cargo volume and its flow structure, required quality level of services, environmental and commercial constraints; in line with available financial resources [6], [7]. The continual monitoring process constitutes only a part, thus most relevant, of the typical full scale terminal design and development project.

The other resource components: overall layout, general plan, zoning and financial profiling, change relatively much slower. Therefor it is impractical to keep the whole terminal design project active and under constant update and adjustment to the rapidly changing operational environment. Preferably choose optimal timing to introduce new solutions and commit to use specific resources, which possess the required competences and skills built on a very specific domain of professional knowledges.

A similar problem appears when resources of a small terminal or dry port is considered: the perceptions are too loose and detalization is too weak to engage specialized consulting services [8]–[9]. At the stage of pre-feasibility studies and general entrepreneur decisions, it is desirable to have simple but adequate tools for quick and reliable assessment for comparing and evaluating a benefits-costs analyses of different technological solutions against scenarios. A full-scale terminal design project would require deep and multi-facets professional knowledge and know-how, but the availability of such tools could be useful only for customers considering to start a large infrastructural project, leading to terminal development.

This paper describes a model and tool based on theoretical principles and practical experiences accumulated by the scientific knowledge, terminals operations and equipment suppliers' know-how.

Methods and materials

The model breaks all terminal container handling operations into the groups defined by the operations through the cargo passes in the terminal — cargo fronts, container yards, depot, inspection zones etc. The total annual cargo Q flow is divided into N partial flows, i.e. $Q = \sum_{n=1}^{N} q_n$. Every partial cargo flow q_n passes the terminal by its own trajectory, that is built of different succession of operations

$Op_n = \bigcap_{l=1}^{L_n} op_i^n$. Operations in container terminal could be divided into three main functions: selection of container from initial position, transportation and putting into new position, or $op_l^n = get_l^n \cap move_l^n \cap put_l^n$.

Every operation l as a link of one operational chain n should have the same hourly throughput capacity $p_i^n = \dfrac{q_n}{365 \cdot 24 \cdot k_n}$, where k_n is the utilization coefficient of astronomical time for this operation.

In its turn, every operation $op_i^n = get_i^n \cap move_i^n \cap put_i^n$ requires the utilization of the different triplet of technological equipment set to get, move and put the containers, and every set should provide the same throughput capacity p_l^n. If the function get is executed by the machine R_t and the hourly rate of this machine in the operational link is r_l^n, then the operation op_i^n will require the $n_t = \dfrac{p_l^n}{r_l^n}$ machines of type t. The same consideration for the functions $move$ and put will define the number of machines of these or other types needed to perform this operation.

Eventually, after breaking the cargo flow into partial flows, disassembling these partial flows into three primal operations, selection of the operation technology (i.e. assignment of equipment type to every function participating in operations), it is possible to calculate the number of machines by type $N_t = \sum n_t$ needed to accommodate the total cargo flow.

Since all the values of operation rates, cargo flow divisions and amounts, utilization and deviations are stochastic, it is useful to use the Monte Carlo techniques in calculations, that would give the estimation of the technological equipment fleet, not as deterministic figures, but as distribution functions. In order to do so the overall variation coefficient should be selected.

The tool further referred as Equipment Calculator, provides both simple deterministic and advanced statistical probability estimations of the resources needed to operate a container terminal. It supports evaluations of several built-in basic conventional cases, but also permits to undertake an in-depth analysis of detailed container flows in terminal with any customized container handling systems. Accordingly, the tool can be used both by inexperienced and professional users at early stage of terminal development or re-engineering projects.

The tool enables to reach the following goals:

1. Estimate equipment, technology and area needed for given (referenced) annual volume
2. Compare alternative equipment and technology impact on the efficiency of terminal operations.

The terminal container flow modelling with Equipment Calculator starts with "General parameters" screen (Fig. 1); language, annual operative days, TEU-factor and variation coefficient.

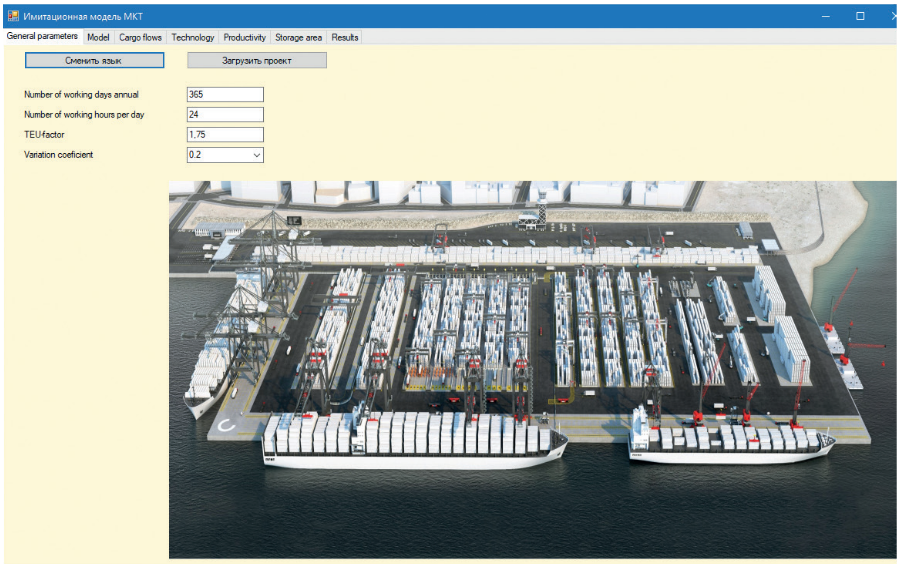


Fig. 1. Main page of the Equipment Calculator

Next screen visualizes and sets the detailed cargo flows passing through a container terminal, dividing flow into typical operations in the terminal; inspection, stripping/stuffing and landside traffic options (Fig. 2).

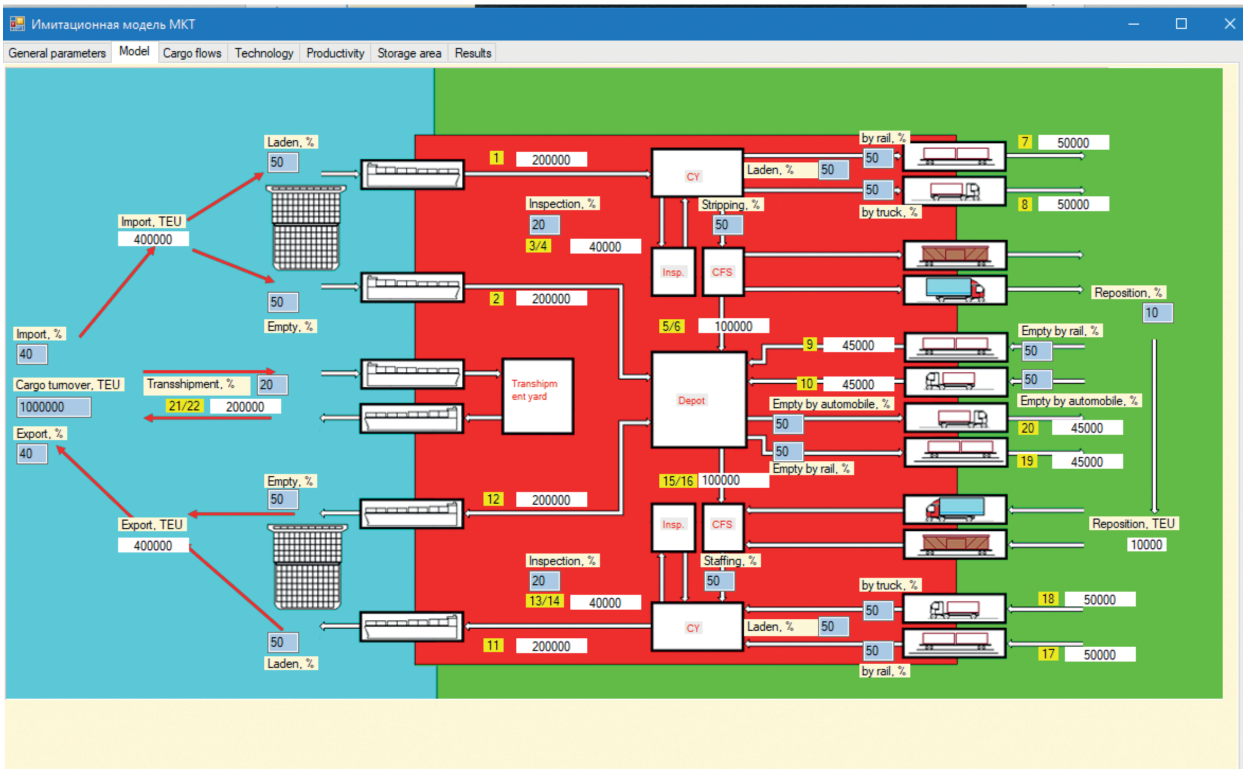


Fig. 2. The graphical model of container terminal

In detail, the model includes list of the most typical activities of a container terminal consisting of technological elements, such as:

– ship cargo handling front at berth;
– truck/rail cargo handling front at landside;
– container yards (dedicated for different type of laden containers);
– container depot for empty containers;
– container freight stations for stripping and stuffing;
– inspection area.

Technological operations connect all these elements into a cargo-processing system, which is the subject of the evaluation. These operations are:

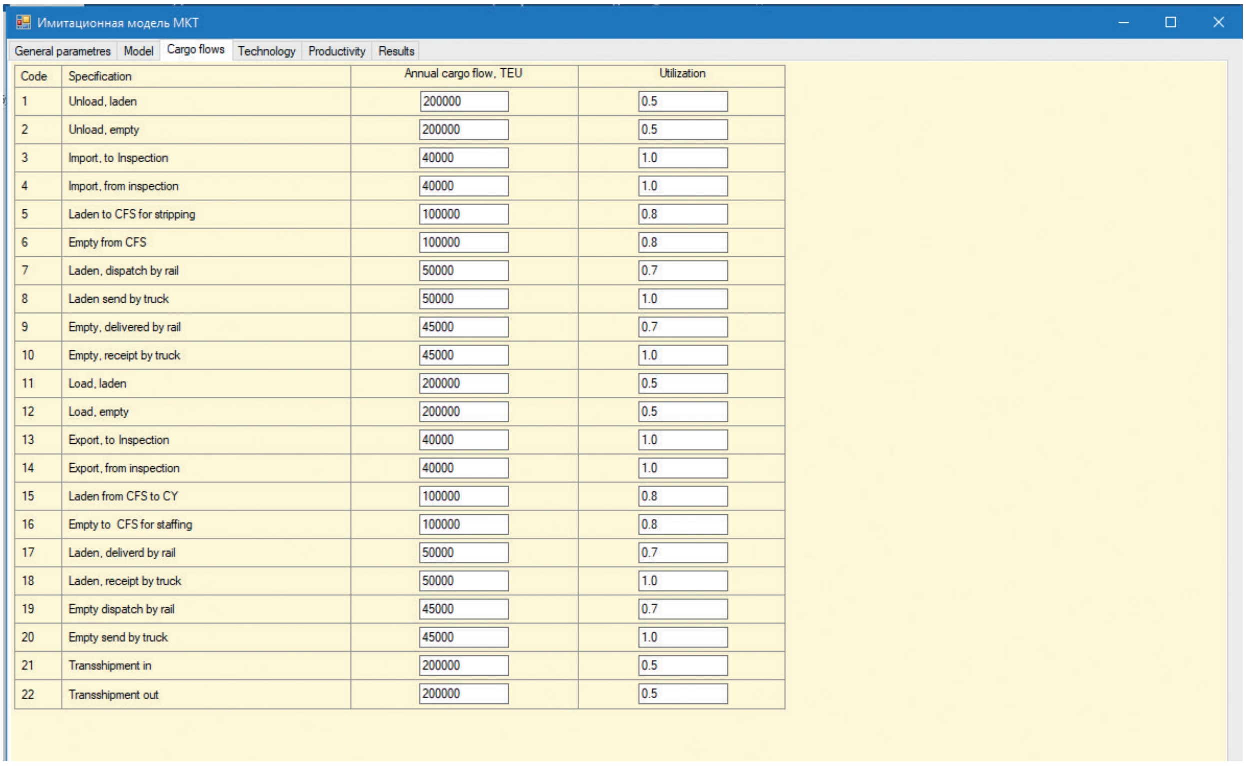
– import and export of laden and empty containers (loading/unloading to/from ships);
– transport laden containers to/from the inspection;
– transport laden containers to CFS for stripping;
– empty/laden containers transportation to/from CFS;
– dispatch/receive laden/empty containers from/to terminal by truck/rail;
– import/export transshipment container to/from terminal.

Different constituting container flow components of the annual throughput pass through the system by different routes. A technologic route is a succession of elements and operations that cargo passes depending on its nature. Empty containers follow one route; reefers go along their own trajectory; containers for stuffing and stripping flow their specific routes.

The leading numeric value of all task-setting procedure at this stage is the annual container throughput volume measured in TEUs. This value is divided into 3 components: import, export and transshipment by inputting their percentage shares.

Accordingly, inputs of percentage shares of empty/laden containers, containers leaving the terminal laden and stripped at CFS, crossing the perimeters on rails or trucks etc. In case no explicit values are known, typical values in industry could be used.

The "Cargo flows" screen (Fig. 3) shows the total annual container flow for every technological operation. One operation may participate in many different technologic routes, while others are involved only in few. Consequently, the same annual cargo throughput could require radically different amounts of technological operations, depending what terminal operations are included.



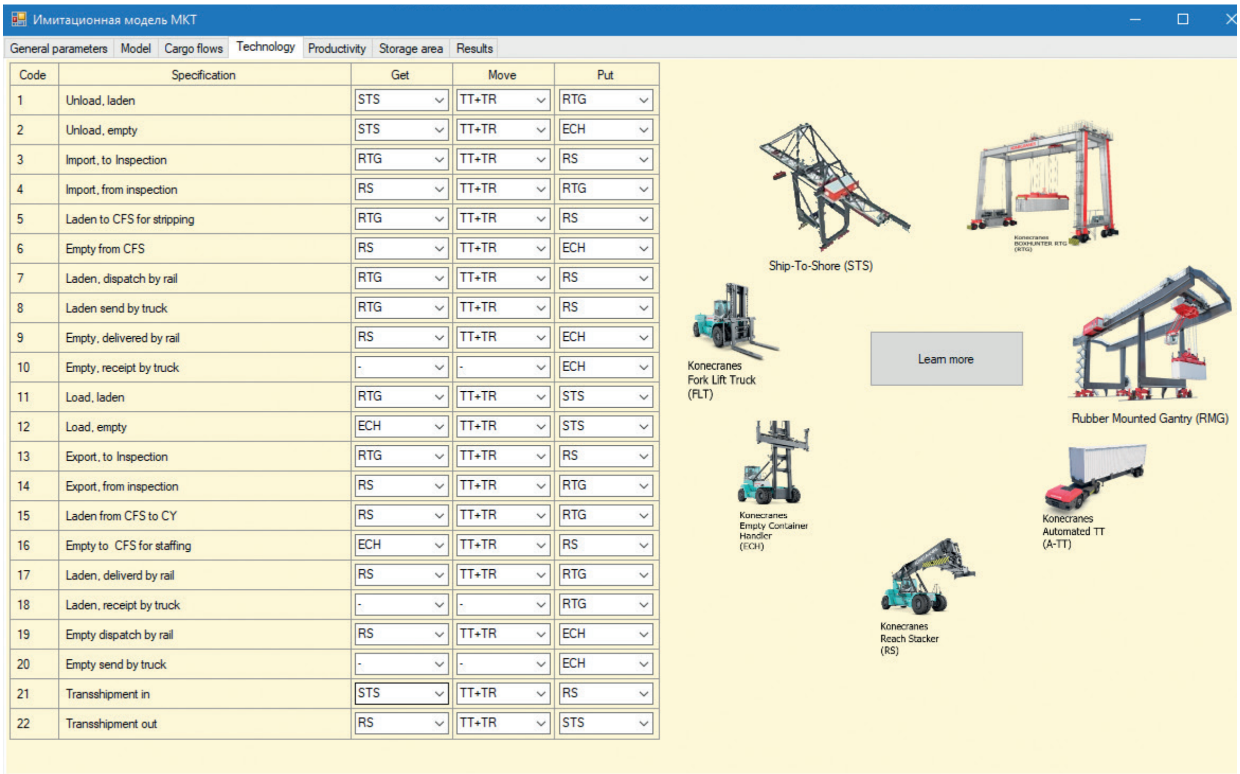
Code	Specification	Annual cargo flow, TEU	Utilization
1	Unload, laden	200000	0.5
2	Unload, empty	200000	0.5
3	Import, to Inspection	40000	1.0
4	Import, from inspection	40000	1.0
5	Laden to CFS for stripping	100000	0.8
6	Empty from CFS	100000	0.8
7	Laden, dispatch by rail	50000	0.7
8	Laden send by truck	50000	1.0
9	Empty, delivered by rail	45000	0.7
10	Empty, receipt by truck	45000	1.0
11	Load, laden	200000	0.5
12	Load, empty	200000	0.5
13	Export, to Inspection	40000	1.0
14	Export, from inspection	40000	1.0
15	Laden from CFS to CY	100000	0.8
16	Empty to CFS for staffing	100000	0.8
17	Laden, deliverd by rail	50000	0.7
18	Laden, receipt by truck	50000	1.0
19	Empty dispatch by rail	45000	0.7
20	Empty send by truck	45000	1.0
21	Transshipment in	200000	0.5
22	Transshipment out	200000	0.5

Fig. 3. Cargo flows in operations

These operation volumes are supposed to be executed during the whole year's period. In the same time, different operations utilize different shares of the astronomic time budget. The ship handling operations, for example, are limited by the berth utilization; the schedule of custom inspections could be not 7/24 but 5/16 etc. The known values (or expert assumptions) of these utilization levels should be provided here in the right column. Every technological operation for its implementation requires a certain set of technological equipment called technological line. Any technological operation implies that a container should be taken from its initial location at some technologic facility (or element), transported to another technologic elements and placed in its designated position there. Every step of this process, i.e. 'get', 'move', 'put', could be performed by different type of technologic equipment. For example, STS or MHC could unload boxes from ship, a set of the terminal chassis tugged by the terminal trucks (TT+TR) deliver them to RTG or RMG operation areas, and the latter place them into stacks of container yard. In another case TT+TR and RTG/RMG could be replaced by reachstackers only. The set of all equipment allocated to handle the containers on the terminal defines the container handling technology.

The efficiency of this container handling technology in many cases is the main subject for study. For the goal of assessment this technology is defined by selection specific machines from the list of available for this operation, as next page "Technology" displays (Fig. 4).

The equipment types are shown in this screen and further data is available by clicking on "Learn more" (Fig. 5).



Code	Specification	Get	Move	Put
1	Unload, laden	STS	TT+TR	RTG
2	Unload, empty	STS	TT+TR	ECH
3	Import, to Inspection	RTG	TT+TR	RS
4	Import, from inspection	RS	TT+TR	RTG
5	Laden to CFS for stripping	RTG	TT+TR	RS
6	Empty from CFS	RS	TT+TR	ECH
7	Laden, dispatch by rail	RTG	TT+TR	RS
8	Laden send by truck	RTG	TT+TR	RS
9	Empty, delivered by rail	RS	TT+TR	ECH
10	Empty, receipt by truck	-	-	ECH
11	Load, laden	RTG	TT+TR	STS
12	Load, empty	ECH	TT+TR	STS
13	Export, to Inspection	RTG	TT+TR	RS
14	Export, from inspection	RS	TT+TR	RTG
15	Laden from CFS to CY	RS	TT+TR	RTG
16	Empty to CFS for staffing	ECH	TT+TR	RS
17	Laden, deliverd by rail	RS	TT+TR	RTG
18	Laden, receipt by truck	-	-	RTG
19	Empty dispatch by rail	RS	TT+TR	ECH
20	Empty send by truck	-	-	ECH
21	Transshipment in	STS	TT+TR	RS
22	Transshipment out	RS	TT+TR	STS

Fig. 4. Technology screen

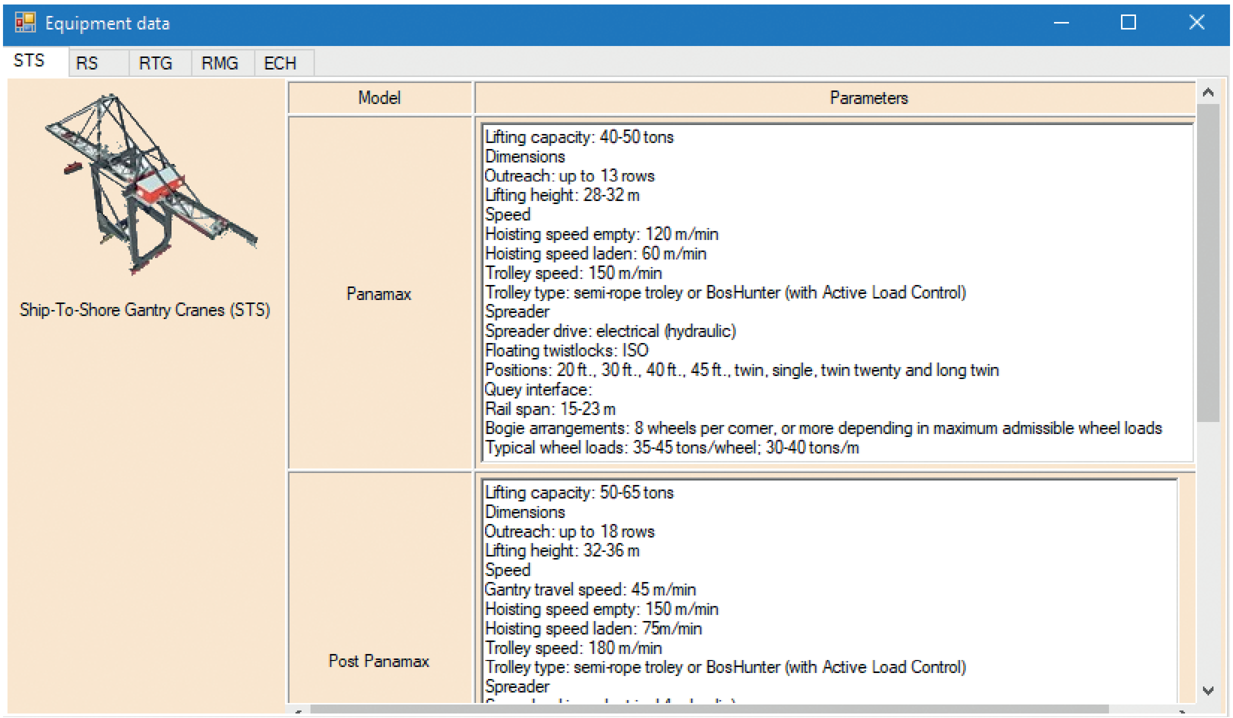
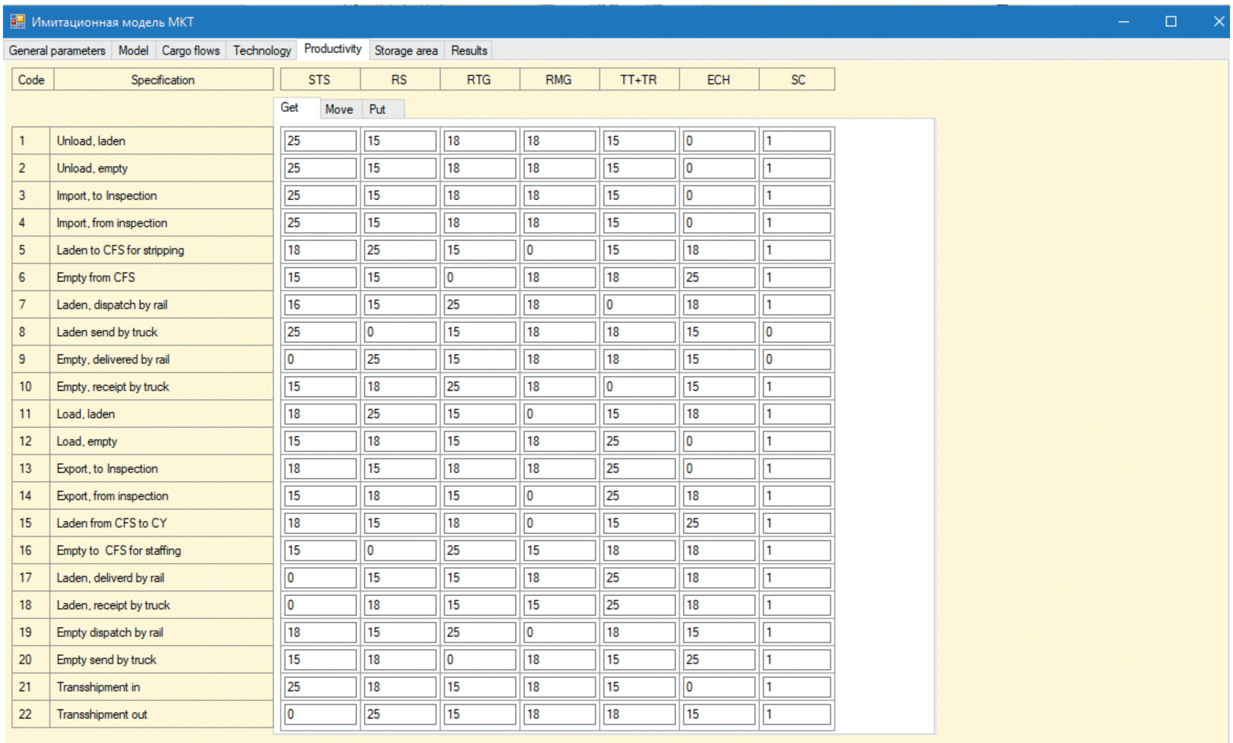


Fig. 5. Description of equipment

The efficiency of container handling technology is one of the main attributes for study. The equipment engaged in container handling operations has different productivity rate measured by number of moves (handlings) per operational hour. Moreover, this productivity depends on its particular location of equipment in operation line. The statistical data on these productivity rates (or assumed references values) should be set for every piece of equipment used in container handling technology in “Productivity” screen (Fig. 6).



Code	Specification	STS	RS	RTG	RMG	TT+TR	ECH	SC
1	Unload, laden	25	15	18	18	15	0	1
2	Unload, empty	25	15	18	18	15	0	1
3	Import, to Inspection	25	15	18	18	15	0	1
4	Import, from inspection	25	15	18	18	15	0	1
5	Laden to CFS for stripping	18	25	15	0	15	18	1
6	Empty from CFS	15	15	0	18	18	25	1
7	Laden, dispatch by rail	16	15	25	18	0	18	1
8	Laden send by truck	25	0	15	18	18	15	0
9	Empty, delivered by rail	0	25	15	18	18	15	0
10	Empty, receipt by truck	15	18	25	18	0	15	1
11	Load, laden	18	25	15	0	15	18	1
12	Load, empty	15	18	15	18	25	0	1
13	Export, to Inspection	18	15	18	18	25	0	1
14	Export, from inspection	15	18	15	0	25	18	1
15	Laden from CFS to CY	18	15	18	0	15	25	1
16	Empty to CFS for staffing	15	0	25	15	18	18	1
17	Laden, deliverd by rail	0	15	15	18	25	18	1
18	Laden, receipt by truck	0	18	15	15	25	18	1
19	Empty dispatch by rail	18	15	25	0	18	15	1
20	Empty send by truck	15	18	0	18	15	25	1
21	Transshipment in	25	18	15	18	15	0	1
22	Transshipment out	0	25	15	18	18	15	1

Fig. 6. Productivity screen

The knowledge of reference task for every operation and machine involved in relevant technological lines defines the operational volumes for every piece of equipment in particular operation. The given productivity of operation in specific location provides the possibility to calculate the number of machines needed for every operation. Adding together the number of machines demanded in all operations enables to assess the total size of the equipment fleet by types.

Usually, the stock size is roughly estimated as $E = Q\dfrac{T_{dwell}}{365}$ determined by the desired dwell time [10]. Different categories of containers (import and export, empty and laden, refrigerated and with dangerous cargo) have different dwell time, so the storage capacities for them should be calculated separately. The simulation defines the maximal one-time storage capacities E_i for all categories of containers.

The operational height H_i for staking containers of a category i enables to calculate the square of the relevant stack measured in terminal ground slots (tgs) as $s_i = \dfrac{E_i}{H_i}$. The net square of one tgs in square meters s_0 enables to calculate the square of the stack foundation (bottom) $s_i \cdot s_0$, of the net stack area. This net area increases due to necessity to have technological passes and aisles which provide the access to containers in the stack and their transportation.

This is the way to calculate the CY area in terminal ground slots. If multiplied by the 'physical' area of tgs S_{tgs} = 15 m^2, it gives the "stack bottom" area or $Stack$ (Fig. 7).

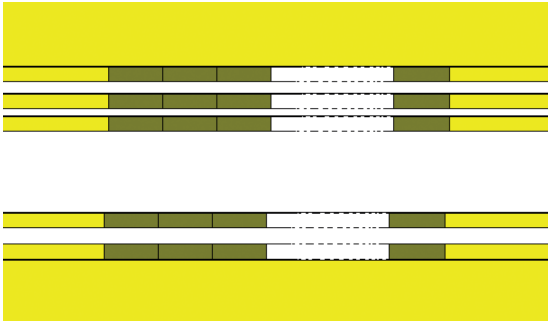


Fig. 7. Net and gross areas of the container stack

This is taken into account by applying a coefficient of cargo handling system $k_1 > 1$ that gives the gross stack area $s_i s_0 k_1$. The typical values of this coefficient for different container handling systems are given by table below (Table).

Coefficients of stacking areas

Stacking technology	L	RS	SC	RTG/RMG
Gross slot area, m2	75	50	37	30
Coefficient	5.0	3,3	2,5	2,0

Thus, the *Stack* area is only a part of the CYnet territory, and this ratio is given by utilization ratio Stack/CYnet (<1) ratio. This gross stack square is only a part of the container yard area, since there are also light-post, transformer and filling stations, pedestrian sidewalks etc. allocated in this zone. The same way: the *CYnet* area is only a part of the CYgross territory, and this ratio is given by utilization ratio CYgross/CYnet (<1) ratio in the screen. The area needed to allocate all these objects could also increase due to non-rectangular shape of the territory. The special "triangulaty" coefficient $k_2 > 1$ combines all above mentioned factors resulting in the container yard net area $s_i s_0 k_1 k_2$, as a component of the container yard operational area.

The sum of these squares for different type of containers $S_{CY} = \sum_i s_i s_0 k_1 k_2$ gives the total square of the container yard. The average statistical ratio of the total terminal area to the area of its container yard $k_3 > 1$ assesses the total area needed for the container terminal as $S = k_3 S_{CY}$. The same way, the *CYgross* area is only a part of the CY geographical territory, and this ratio is given by utilization ratio CYgross/S (<1) ratio in the screen. All these parameters could be keyed in on the page "Storage area".

Results

The results of calculations appear on the "Results" screen. By clicking the 'Run' box, the tool performs the simulation process which underlines the whole calculation procedure applying the variant coefficient (set on "General parameters" screen) on each input flow component parameter.

There are two screens representing these results, "Equipment" and "Storage area", which can be selected and toggled between. The results are shown: a) by pressing "Storage area", the characteristics of the area needed for allocation main storage zones (Fig. 8) and b) by pressing "Equipment", the equipment fleet assessment (Fig. 9).

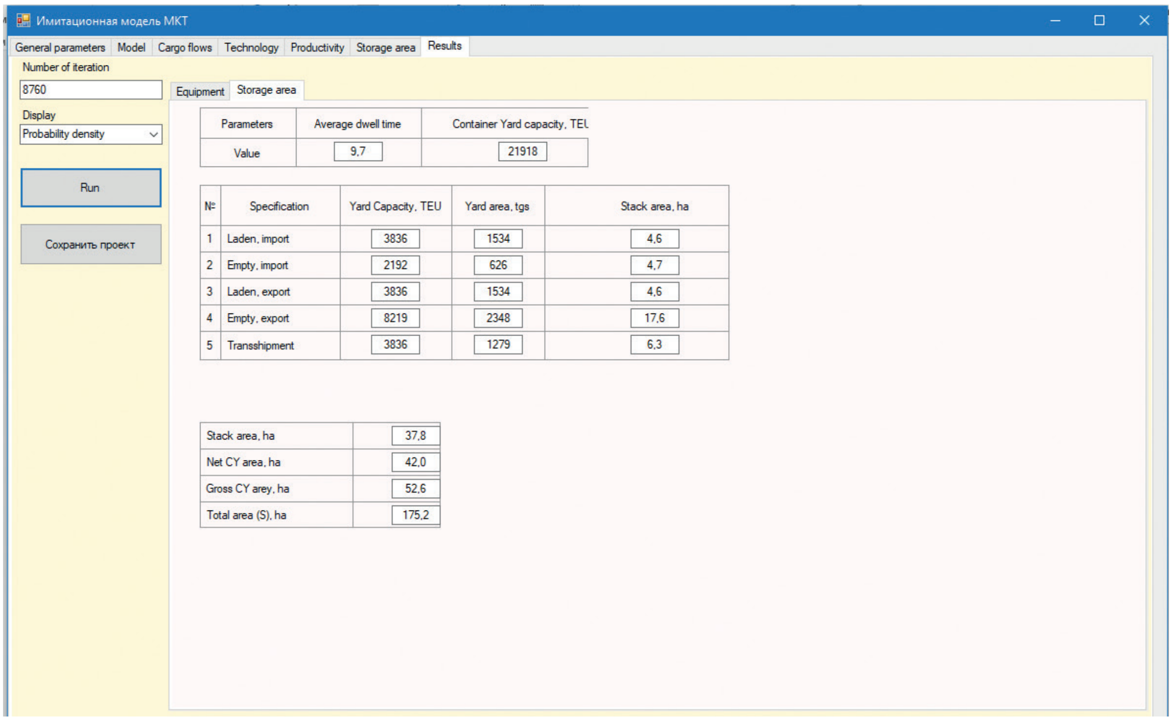


Fig. 8. The results of calculation of terminal area

ВЕСТНИК
ГОСУДАРСТВЕННОГО УНИВЕРСИТЕТА
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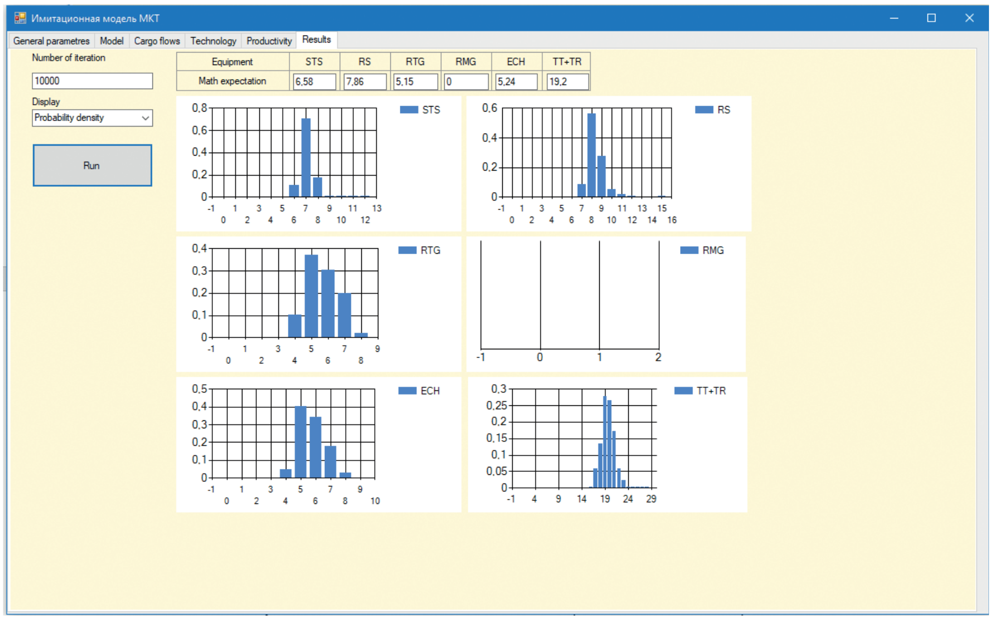
The results of these calculations provides either deterministic values of the required amount of equipment or relevant stochastic functions. In reality, all cargo flow volumes, utilization and equipment productivity are not deterministic, but stochastic values. As stochastic values, these parameters assume certain level of variation. This level of variation determines the range of the parameter fluctuations. In different cases the combinations of these stochastic values would results in different output values. The execution of sufficient number of these experiments, as mathematical Monte-Carlo technique assumes, provides the assessment of required characteristics as random (stochastic) values. The distribution of these values could be presented either by the density of probability (Fig. 9a) or integral probability function (Fig. 9b).

a)



b)

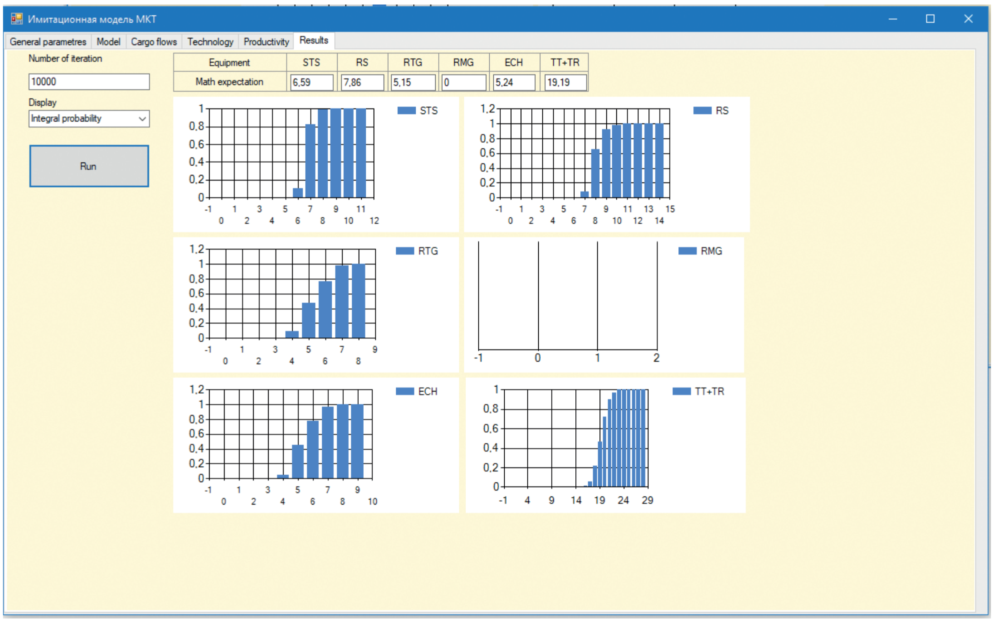


Fig. 9. Screen of equipment fleet size:
a — as probability density; *b* — as integral probability functions

It is possible to select density or integral probability, as well as number of Monte-Carlo experiments (iterations). The integral probability functions in some cases are more convenient since it tells what is the probability that a particular number of machines would be sufficient.

The level of variation is set at parameter selection screen, together with TEU-factor (amount measured in TEUs divided by amount measured in boxes), number of working days in year and operational hours in a day. Specifically, this is a referenced value of variation coefficient which is the ration oa the standard deviation to mathematical expectation. This value is set at the initial page of Equipment Calculator.

Conclusions

1. The constant terminal operations monitoring and the need for modernisation and timly decision to start the developmnet project of container terminal can be provided by analysis of required resourses.

2. The analysis should consider the quality of services and efficiency operations of container terminal, the technology of each operation and the variation of container flow and equipment productivity.

3. These calculations can be provided by the simulation models which consider all the specific features of the container terminals activity.

4. The theoretical knowledges and practical know-how embeded in the model allow it to be used not only by the professional port designers and consultans, but also by the operational departments of the terminal itself.

5. The model described in the paper assumes the on-time updating of the equipment parameters database and operational indicaters that is realized by the itput both from the equipment manufacturers and terminal operaters.

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