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INFLUENCE OF A CARGO PLAN ON PORT OPERATIONS

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Nowadays, with overall introduction of patented technologies for the production of goods, the possibility of reducing their cost in order to maintain a competitive position in the commodity markets is supported by the rational organization of transportation. Thus, the transport component in the final cost of transported goods has to be reduced. At the same time, when using the same handling, lifting and transporting equipment from a limited number of the global manufacturers, the possibility of reducing the cost of transport operations (both shipping and handling, including loading/unloading) exclusively depends on not on the set, but on the rational use of the equipment. One of the possible mechanisms for rationalizing the loading and unloading operations carried out on container terminals is the rationalization of cargo plans of the serviced container ships. The versatility of their implementation is explained, first of all, by severe requirements for the safety of navigation, which determine the provision of the necessary stability, unsinkability, the absence of a heel and different that could interfere with the berth operations, the required sitting of the ship in the water, etc. On the other hand, the rational allocation of containers in the hold slots and on the hatches covers of the container ships, corresponding to the voyage rotation (the sequence of visiting terminals on the trip in progress), provides an increase in the share of productive movements of handling, lifting and transporting equipment, reduces the required time for a ship to be under loading and unloading operations, which reduces the time of a group of ship trips on a string.

Such calculations are complicated by the fact that the handling equipment, used for loading and unloading operations on a ship, operates relatively autonomously, with each unit allocated for its own section of the ship (bay). Thus, the task can be solved only in a complex manner, in the context of the task of cranes allocation over the berth. The issues of cargo planning of liner container ships from the standpoint of reducing the time of ship's turnaround time due to rational assignment and use of terminal handling equipment are studied in the paper.

Keywords: container shipping, cargo plan, handling of ships in the port, turnaround time.

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ВЛИЯНИЕ КАРГОПЛАНА СУДНА-КОНТЕЙНЕРОВОЗА НА СКЛАДСКИЕ ОПЕРАЦИИ ТЕРМИНАЛА

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Проанализирован один из вариантов современных унифицированных технологий производства потребительских товаров, предусмотренных для снижения их конечной стоимости, которая, в свою очередь, является основой рыночной устойчивости компании-производителя, в основном лишь логистической *составляющей, и в первую очередь стоимости транспортировки товаров от места производства к месту потребления. Отмечается, что в то же время использование для перевозки, перевалки и внутритерминальной транспортировки грузов унифицированного оборудования, получаемого от ограниченного числа производителей, переводит эту задачу в плоскость рациональной организации его использования. Рассмотрен один из наиболее значимых механизмов оптимизации погрузочно-разгрузочных операций в этих условиях, такой как согласование порядка выполнения технологических процедур контейнерного склада с содержанием «Грузового плана» обрабатываемого терминалом контейнерного судна. Подчеркивается, что вариативность способов формирования «Грузового плана» обусловлена жесткими требованиями обеспечения мореходности судна (его устойчивости, отсутствия крена, дифферента, изгибающих, прогибающих, скручивающих моментов, размещения специальных грузов и др.). Размещение контейнеров в слотах судна под палубой и на люковых крышках, выполняемое в соответствии с ротацией портов на маршруте, определяет доли производительных и вспомогательных операций всего состава подъемного и транспортного оборудования, размещение которого для причальных операций определяет время обработки судна в порту и, соответственно, рациональное количество судов на конкретном маршруте (стринге). Отмечается, что эти расчеты осложняются тем, что размещение оборудования для причальных операций обработки судна производится в группе относительно независимых секций (беев), что требует решения не локальной, а глобальной задачи оптимизации размещения кранажа на причале.*

В работе проанализировано влияние, оказываемое каргопланированием контейнерных судов, на темп причальных и складских операций. Показано, что заблаговременное получение информации о «Грузовом плане» позволяет к моменту подхода судна сформировать специальный штабель престакинга, представляющий собой инверсную структуру по отношению к плану погрузки, что позволяет выполнять погрузку судна без дополнительного перемещения блокирующих контейнеров, т. е. за минимально возможное число движений. Как следствие, погрузка судна выполняется в кратчайший интервал времени, повышая тем самым качество оказываемых терминалом услуг и укрепляя его рыночную позицию. Отмечается, что результатом является рост общего количества перемещений контейнеров, поскольку формирование штабеля престакинга требует примерно такого же количество движений, как и прямая доставка контейнеров из штабелей склада, и погрузка на судно, к которому добавляются движения для перемещения из штабеля престакинга на борт судна. Тем не менее полученные в результате исследования результаты позволяют использовать для обработки груза существенно меньшее количество оборудования, концентрируя его в период обслуживания судна у причала.

Ключевые слова: контейнерные перевозки, грузовой план, обработка судна в порту, время стоянки.

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Introduction

The issues of rationalizing cargo planning are well represented in modern applied scientific researches. Modern works are dedicated both directly to the ships' cargo planning task [1] and connecting land vehicles [2], [3]. A number of studies cover the optimization of the interaction of terminal equipment involved in the production of loading and unloading operations [4]–[7]. In this context, the issues of improving the organization and control of terminals operations are considered [8]. A number of ongoing studies are tied to specific terminals or geographic areas [9]–[11].

Consignors and consignees, although they are the principals of transportation, delegate the organization of this process to specialized intermediaries, most often freight forwarders. The freight forwarder directly or indirectly (through yet other intermediaries) enters into negotiations with the commercial services of the shipping line, stipulating the cost and time parameters of transportation. The cargo accepted by the shipping line for transportation is delivered to the seaport specified in the terms of the contract for delivery to the specified port of destination. The transportation of containerized cargo itself is most often carried out along a predetermined route (string), the configuration of which is chosen by the marketing departments of the shipping line according to the criterion of guaranteed availability of cargo flows.

When transporting containers in this pattern, each ship operating on the line moves from port to port along some predetermined route, which is usually looped (pendulum route). When the ship navigates from a port to the next port over this route, there are both containers that must be unloaded at the nearest point as well as containers that will remain on board after calling this port (fig. 1).

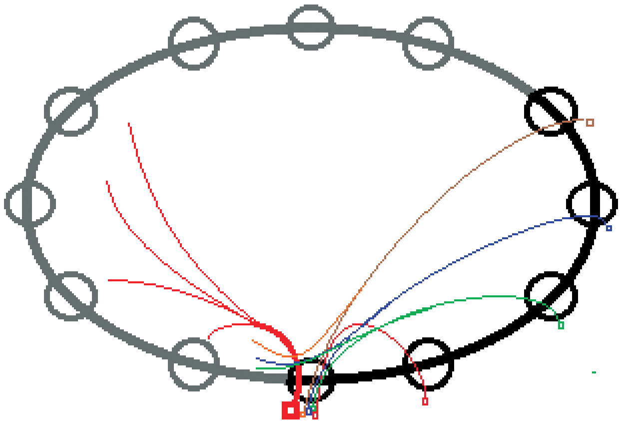

Fig. 1. Routes of passage of containers through a separate port

As can be seen from this figure, from logistic point of view all containers on a ship entering the port can be divided into three categories:

– containers arriving by ship and bound to the given port (unloaded);
– containers remaining on board designated further ports of the route (transit);
– containers departing by ship and following to further ports of the route (loaded).

Information about the availability of cargo at each port of the route and the final point of their delivery is transmitted to a general line management service. At each moment in time, the *line manager* has complete (for a specific moment in time) information about all received orders for the carriage of goods between points of the circular route. This allows him to ensure rational loading of the ship at each site, more or less appropriate amount for taking on board in each port. The cargo remaining not loaded onto the ship is waiting for its turn, i. e. for the next ship of the line to come.

The information to the line manager is provided by the *local planner* which maintains direct communication with the relevant port forwarder. The actual transportation is performed by the ship, the *administration* of which ensures the safety of navigation and the security of cargo. Loading and unloading of the agreed cargo at the port is performed by the *terminal operator*. The position on board of the vessel and the attributes of each transported container are recorded in a special document shared by all participants in of the transportation process called a cargo plan (stowage plan, bayplan, loading plan). The cargo plan is primarily intended to guarantee safety of navigation: to ensure the permissible values of heel, trim, metacentric height, breaking and twisting moments, the proper allocation of dangerous goods, visibility from the bridge and other parameters important for the ship's administration (fig. 2).

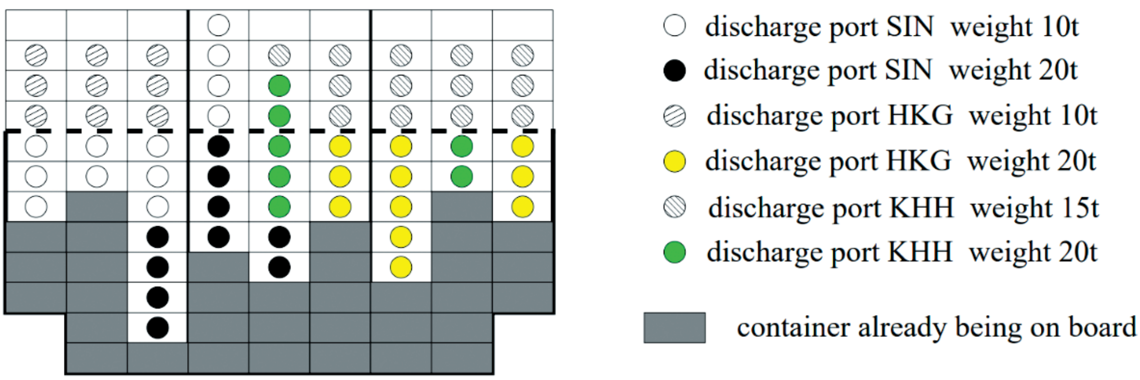

Fig. 2. Example of one bay's cargo plan

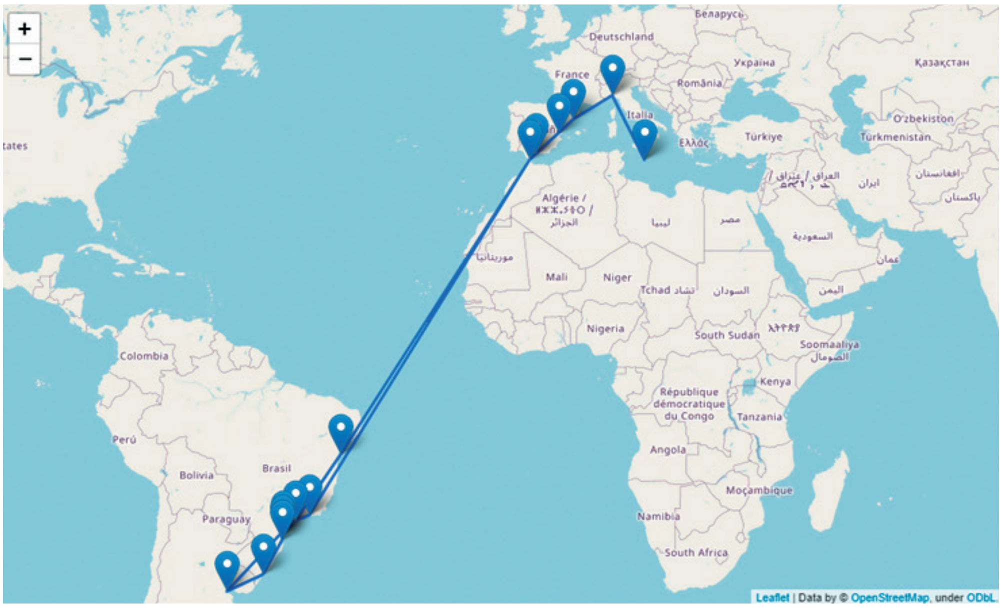

Fig. 3. Example of the string

In addition, to simplify discharging, containers bound for discharging at the nearest port preferably should tend to be located in the upper tiers of the stacks above the deck, and/or entirely fill one bay. The peculiarities of the organization of liner shipping and the number of ports of call make the task even more complex (fig. 3).

Methods and materials

The problem is that after unloading at a port, the cargo plan will have to be rebuilt: some containers will remain on board in their unchanged position, some of them will be moved to new positions to provide access to the unloaded ones. The situation is no simpler with containers awaiting loading: some of them may not yet arrive at the port, while others may not have reliable information on weight and commercial parameters. As a rule, having a complete understanding of the unloaded containers and a general understanding of the containers awaiting loading, the line manager forms a preliminary cargo plan, which indicates only the general weight characteristics of the containers expected to be loaded (light, medium, heavy) and, possibly, the port of destination.

The local planner, having more complete operational information about the available containers and their status, fills this preliminary plan with specific containers, forming an accurate (“final”) plan, or rather its draft. This draft is sent to the central planner for approval, since the available containers, refined parameters and the wishes of the local forwarders may cause deviations from the expected characteristics of both the preliminary and the proposed final cargo plan. In the course of the procedure for agreeing on the introduced changes between the line manager and the local planner, an important role is assigned to the ship administration, which has the decisive word in the approval of the cargo plan from the point of view of the safety of navigation.

As a rule, by the time the ship is prepared for unloading, the cargo plan of the trip to the next point of the route must be agreed upon. At the same time, the cargo plan upon arrival and the cargo plan upon departure from the port are but static lists reflecting the initial and final state of the cargo on board the vessel during its handling port. For the port operator, it is not these static states that are more important, but the operating procedures themselves, by which these states are achieved. First of all, these include the plan for unloading the vessel — the sequence of removing containers from the ship, possible movement of blocking containers to new positions on the ship, temporary unloading of blocking containers to the berth. All these operations must be carried out taking into account the factors mentioned above — permissible values of heel, trim, metacentric height, breaking and twisting moments, visibility conditions for ship-to-shore crane operators, safety precautions during work, etc. An incorrect sequence of unloading or loading containers onto a ship can lead to dire consequences (fig. 4).

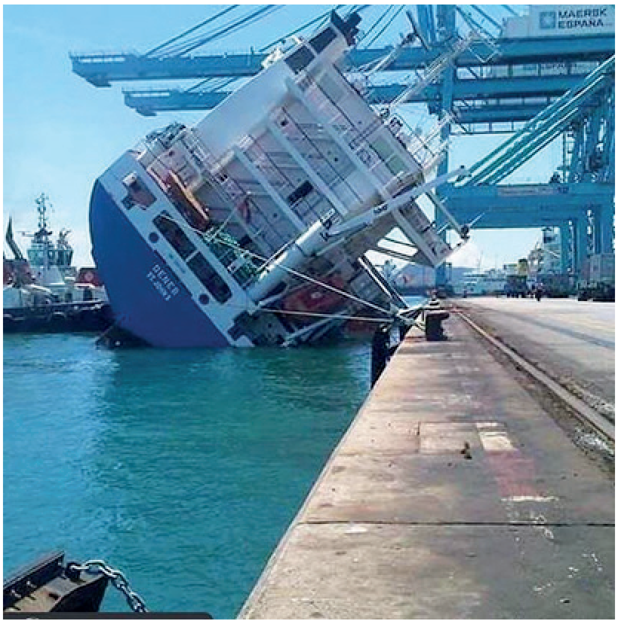

Fig. 4. The consequence of a wrong cargo planning

In addition, cargo operations are not carried out in a single sequence: they are divided into separate sub-sequences corresponding to the allocation of ship-to-shore cranes for work at the zones of the ship's bays. Exactly the same problems arise when loading containers, supplemented by the problem of ensuring maximum loading of the handling equipment distributed for work on the ship. Thus, in addition to static cargo plans of entry and exit, handling a ship in port requires two operational sequences: an *unloading plan* and a *loading plan*.

The dispatch service of the container yard (CY) of the container terminal must timely ensure the implementation of the relevant transport and cargo operations, for which it must formulate plans for their implementation in one form or another (fig. 5).

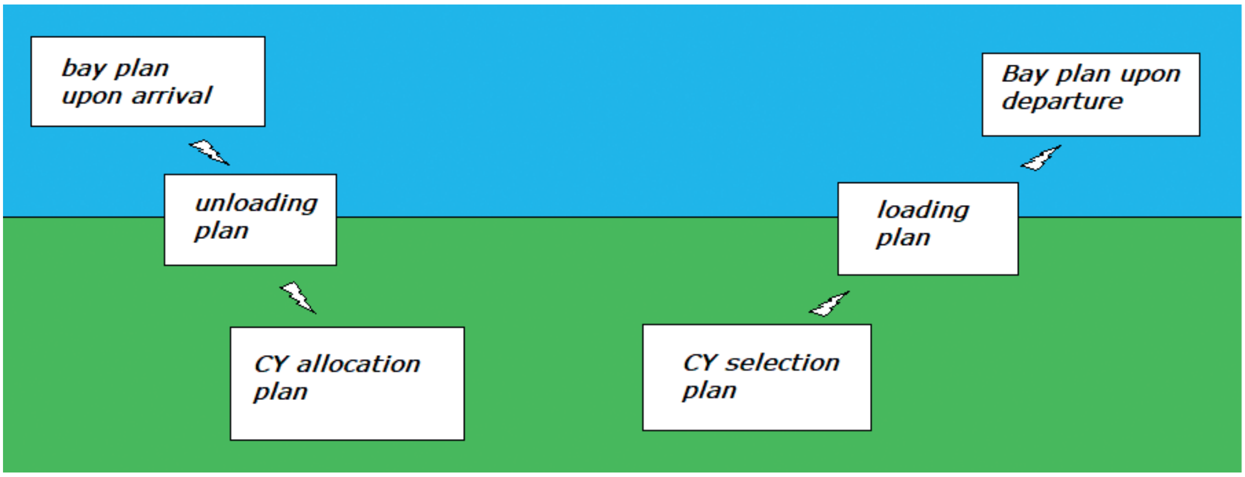

Fig. 5. Operational plans for handling the ship in the port

The solution to all the above problems is already quite difficult, but this is not all: for the timely supply of containers for loading onboard the ship, the container operator must perform a lot of technological operations to unblock target containers, picking them from stacks, and transport them to the operation area of ship-to-shore cranes. Simply specifying the sequence of containers to be moved does not mean solving the problem: as a rule, it is impossible to perform these actions at the pace of berth operations, and the only solution is to form a special pre-stacking stack: containers pre-selected from the total field of stacks of a container warehouse and moved to a stack located in the immediate vicinity from the area of berthing operations.

However, simply moving all export containers onto a stack closer to the loading area does not provide a solution. In this stack, containers, which, according to the cargo plan, should be located in the lower tiers of the stack on the ship, must be located above, i. e. the structure of the pre-stacking stack should be strictly inverse to the cargo plan on departure. More precisely, it must be the inverse of the order indicated in the loading plan (fig. 6).

a) b)

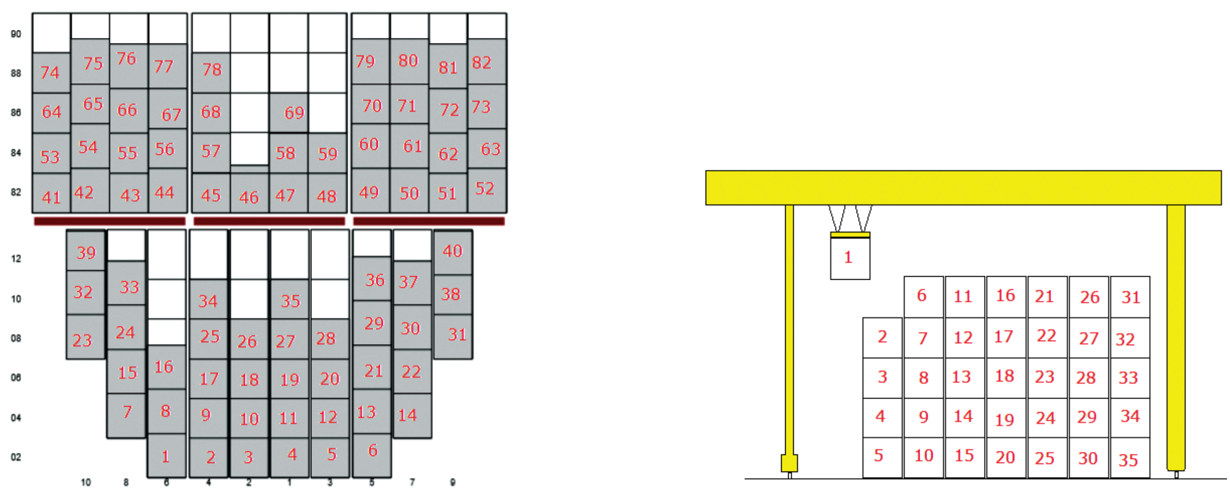

Fig. 6. Stack structure on board the vessel and terminal pre-staking area:
a — ship's bay; *b* — container stack

At the same time, the formed sequence of loading on board the vessel is not a strictly linear sequence: its constituent containers are distributed over separate zones of the bays, determined by the placement of berthing equipment for working on the vessel. As a result, the specified sequence is split into the corresponding number of parallel and independent sub-sequences. Each such sub-sequence specifies the operation procedure for one technological line (STS handler). Moreover, the handler can serve the bays assigned to it in a different order, which leads to the splitting of the specified sub-sequence at one more level, which determines the order of handling bays (which of them will be handled first, second, etc.). Finally, the cargo plan of the bay and the chosen loading procedure (horizontal or vertical) determines the sequence of containers that must be supplied to the working area of the handling equipment (taken from the pre-stacking stack). And this sequence, finally, completely determines the structure of the latter: dividing the entire sequence into segments equal in length to the technical height of the stack, taken in inverse order, which form the position of the containers over each slot. The pre-staking sequence must be inverse to these particular subsequences. In turn, the maximum height of one section of the pre-stacking stack splits these subsequences into even smaller parallel subsequences (fig. 7).

By the official norms of technological design of commercial seaports, the handling time of the design vessel $T_{handl.M}$ in hours is prescribed to be determined by the formula:

$$T_{handl.M} = \frac{2Dk}{M_m}, \tag{1}$$

where D — container capacity of the vessel, boxes;

k — the capacity utilization factor of a container ship, which is recommended to be 0,85;

M_m — the intensity of cargo operations (net) in containers per hour, determined by the formula

$$M_m = P_l N_l, \quad (2)$$

where P_l — operational productivity of the technological line, cont./*h*;

N_l — the average designed number of allocated technologic lines is taken according to table 1, as well as the values of technical performance.

Table 1

Normative reference data from the Technological Design Standards

Type of container ship	Average no of lines, N_l	Technical rate, P_l
CS-300–400	1,4	25–28
CS-700	1,8	25–28
CS-1200–1400	1,9	28–32
CS-1800–2500	2,5–2,7	30–35

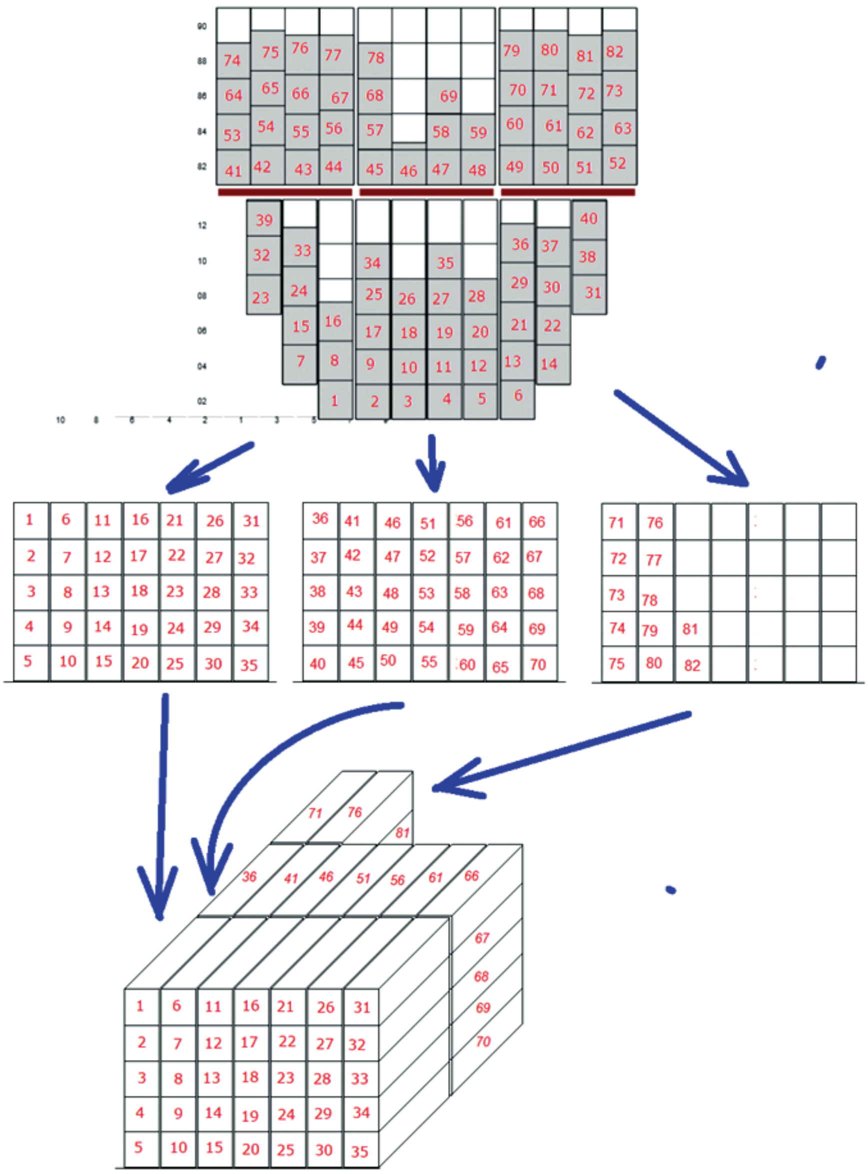

Fig. 7. Stack structure on board the vessel and terminal pre-staking area

An approximate calculation of the ship's handling time at berth, based on these data and serving as the basis for assessing the capacity of berths and ports, is given in table 2.

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

Table 2

Normative reference data from the Technological Design Standards

Capacity, box	Average no of lines	Technical rate, moves/*h*	Berth time, *h*
350	1,4	25	20
700	1,8	26	30
1300	1,9	28	49
2150	2,6	32	52

At the same time, in almost no specialized container port, specially built ships with a capacity of more than 1,500 TEU are unloaded and loaded completely. Moreover, the determining factor of the “size of a ship call” (the total number of unloaded and loaded containers) is the ability to process it in 20–22 hours. In this case, taking into account unproductive operations (mooring and unmooring, idle and downtime, commission work, etc.), the ship’s turnaround time is limited by one day, which is extremely convenient for planning the work of ships on the lines. Based on the foregoing, the time of the ship’s berth time will be determined by the duration of the unloading and subsequent loading of the limiting line, i. e. the unloader handling the longest sequence of handling a group of bays. It is no longer possible to reduce this time, since the placement of the second unloader over the selected group of bays is unacceptable.

Calculations carried out on the basis of the collection of statistical data on of container ships’ voyages show that several hundred containers from one bay are unloaded and loaded in an average port, and one STS handler allocated for 2–3 bays. Thus, one handler is expected to perform about 300 movements to complete the prescribed task. With an average productivity of 25 movements per hour, this requires 12 hours of work per ship. Taking into account work interruptions and unproductive movements (removal and installation of hatch covers, movement of stevedores on board and back, transfer of gears between the ship and the shore, shifting on board or over the berth, etc.), this fits well with the commercial requirements for completion of work in 24 hours on the most labor-intensive link. This is fully confirmed by the collected statistics on the handling of ships in the port.

As it follows from the discussion above, the structure of containers allocation in the slots of pre-stack from the container operators’ point of view is totally dictated by the requirements of cargo plan and loading plan associated with it. This set not only the structure, but also the sequence of the pre-stack formation, i. e. the order of selection and transportation of the required containers that would allow to realize the designated structure of the stack taking into account the technologic equipment used in the terminal.

The conducted considerations show that this sequence from the terminal point of view is pseudo-stochastic, since the terminal operator is not involved in the selection of containers to be loaded onboard the ship. Accordingly, for the purpose of the study of inner regularities of container selection from the stacks this sequence could be gained by the random generation mechanisms without violation of any general principles of terminal operations.

An important circumstance is that forming the pre-stack by the stacking machines with the access from above (RTG, RMG, SC) there is no rigid sequence of container allocation. For placement into the ground tier of the pre-stack any listed container (fig. 8) could be selected from the stacks of the main container yard.

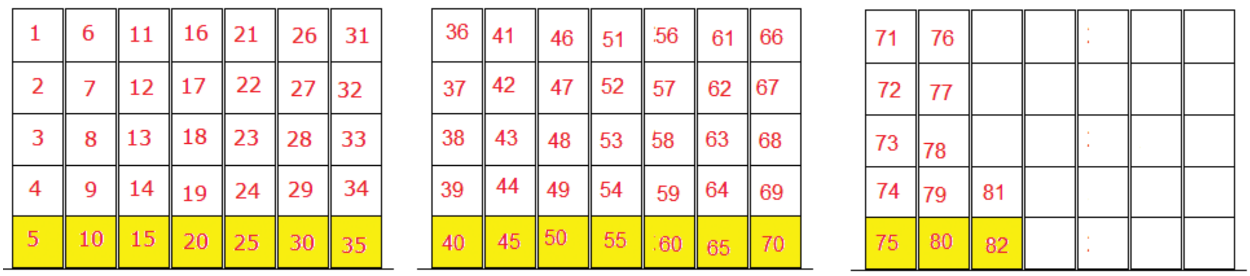

Fig. 8. Possible candidates for selection on the first step of pre-stack formation

Furthermore, if at any further step of this procedure a certain amount of container is placed in the pre-stack, the possibility to select one container from several one remains (fig. 9).

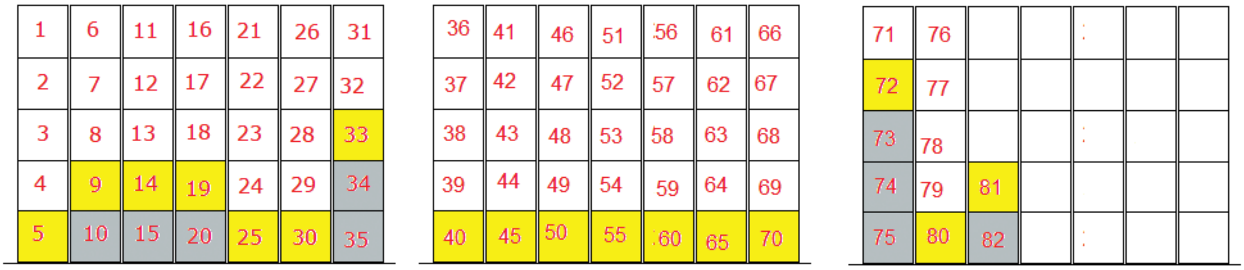

Fig. 9. Possible candidates for selection on middle step (10th) of pre-stack formation

From the candidates marked yellow in Fig. 8 and 9 for the transition from the mains stack area those are selected which are easiest to pick up. For example, it could be the container sitting in the upper tier of the stacks. If there are several containers like that, the one closest to the pre-stack area will be selected. When there are no requested containers in upper tiers, the ones blocked by minimum of other containers will be searched. The shifting of the blocking containers to clear the access should be done so that it would cause minimal problems of the candidates on the following steps. In other words, the algorithms of destination position should not be “greedy”, optimizing the criteria oa current step only.

Discussion

As we have showed, the ship handling time is determined by the time needed to serve the bay with maximal call size (i. e. number of unloaded/loaded container). Accordingly, for the purpose of this study we could address only one bay demanding the maxima; amount of containers for loading. The number of technological lines working on ship is determined by the number of STS handlers allocated for berth operations. A line consists of one STS (for loading), horizontal transportation vehicles (transit between CY and the berth), stacking machines (selecting the containers from the stacks). The equipment of the technological line should enable permanent operation of STS. Mathematically this condition is:

$$Q = k_{util}^{sts} N^{sts} P^{sts} T = k_{util}^{TT} N^{TT} P^{TT} T = k_{util}^{CY} N^{CY} P^{CY} T, \quad (3)$$

where Q — cargo flow, boxes;

k_{util}^{x} — utilization of operation link x;

N^{x} — number of machines engaged in link x;

P^{x} — productivity of one machine in link x, move/h;

T — time of operation.

This condition states that through the loading operation (STS), transportation (TT) and selection (CY) for the time *T* there passes the same container flow *Q*. Since for the case of one bay that we study $N^{sts} = 1$ and $k_{исп}^{sts} = 1$ (there are breaks and no travels between the bays), these conditions could be written as:

$$1 \cdot 1 P^{sts} T = k_{util}^{TT} N^{TT} P^{TT} T = k_{util}^{CY} N^{CY} P^{CY} T; \quad (4)$$

$$P^{sts} T = k_{util}^{TT} N^{TT} P^{TT} T = k_{util}^{CY} N^{CY} P^{CY} T; \quad (5)$$

$$P^{sts} = k_{util}^{TT} N^{TT} P^{TT} = k_{util}^{CY} N^{CY} P^{CY}. \quad (6)$$

Eventually, $N^{TT} = \dfrac{P^{sts}}{k_{util}^{TT} P^{TT}}$ и $N^{CY} = \dfrac{P^{sts}}{k_{util}^{CY} P^{CY}}$ where $k_{util}^{x} \le 1$ is determined by the condition of the integer number of equipment pieces. Here P^{CY} is the commercial productivity, i. e. the number of containers, passing from the CY through inner transportation to berth operational area. The commercial productivity is connected to the effective productivity of the stacking equipment by equation $P^{CY} = s \cdot P_0^{CY}$, where *s* is the selectivity (ratio between number of commercial moves and total number of moves N, or $s = \frac{1}{N} \le 1$). If, for example, $s = 0,5$, then the commercial productivity is only a half of the effective productivity, which would require the increase in the number of stacking machines involved in handling:

$$k_{util}^{sts} P^{sts} = k_{util}^{TT} N^{TT} P^{TT} = N^{CY} P^{CY}. \quad (7)$$

If the number of machines engaged in transportation or selection is not sufficient (i. e. lower than the calculated values), then respectfully limited would be the cargo flow that could pass through this link. In this case the full utilization of equipment will be observed in this limitative link. For example, the deficit of stacking machines could be described as:

$$k_{util}^{sts} P^{sts} = k_{util}^{TT} N^{TT} P^{TT} = N^{CY} P^{CY}. \quad (8)$$

Accordingly, the commercial productivity of the STS handler would drop from its effective productivity due to idle time, or $P_1^{sts} = k_{util}^{sts} \cdot P^{sts}$. As the consequence the time of the bay loading will increase in respect to the estimated value or $T_1 = \frac{E}{P_1^{sts}} \ge \frac{E}{P^{sts}} = T_0$.

When working with the containers in pre-stacking mode, the selectivity always $is = 1$, so the commercial productivity remains equal the efficient one. Respectively, this in one case enables to provides the full utilization of the STS handler by lower number of stacking machines, and in the other case (with the deficit of them) to reduce losses of the productivity.

Conclusions

1. The sequence of tasks when handling a container ship in the port is determined by its cargo plan.
2. The practice of cargo planning and commercial operation of a ship on a container line determines the volume of loading and unloading operations for groups of adjacent bays, for work on which ship-to-shore cranes are allocated.
3. Estimation of the time of cargo operations when handling a container ship is determined by the limiting technological line that receives the maximum operational task.
4. Normative documents governing the rules for calculating the time of carrying out cargo operations and serving as the basis for calculating the throughput of a container terminal are based on incorrect assumptions about the nature and conditions of commercial operation of a container ship.
5. The research carried out by the authors makes it possible to clarify the methods for calculating the handling time of ships at specialized container terminals.

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