

Influence of a cargo plan on the container ship port turnaround time

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Abstract. Nowadays, with 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 is reduced. At the same time, when using the same handling, lifting and transporting equipment from a limited number of global manufacturers, the possibility of reducing the cost of transport operations (both shipping and handling, including loading/unloading) depends only on their rational use. One of the mechanisms for rationalizing the loading and unloading operations carried out by container terminals is the rationalization of cargo plans of the serviced container ships. The versatility of their development is determined, first of all, by high requirements for the safety of navigation, which determine the provision of the necessary stability, unsinkability, the absence of a heel and difference that interfere with the work, the required sitting of the ship in the water, etc. On the other hand, the rational placement of containers in the 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 during the loading and unloading operations on a separate ship operates conditionally autonomously, each unit - for its own section of the ship ("bay"). Thus, the task can be solved only in a complex manner, coupled with the task of cranes allocation over the berth. The paper studies 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 port handling equipment.

1 Introduction: the problem of liner transportation of container cargo

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

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the interaction of terminal equipment involved in the production of loading and unloading operations [4, 5, 6, 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, 10, 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 and containers that will remain on board after calling this port.

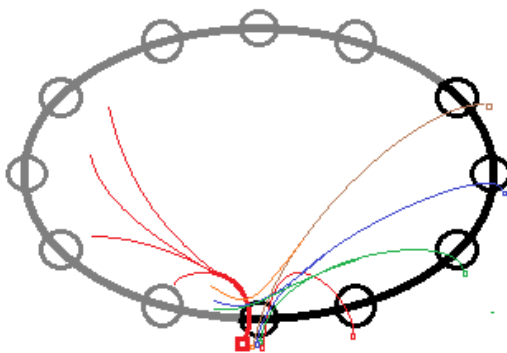


Fig. 1. Routes of passage of containers through a separate port.

The figure above shows that all containers on board are divided into three categories accordance to logistics types.

- Containers – to be discharged (unloaded) at port of call;
- Containers in transit and containers remains on board to be delivered to the further ports of call;
- Containers to be loaded at the port of call and to be discharged at the further ports of call.

General line management service is informed about the availability of cargo at each port of the route and further ports of discharging.

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, choose 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 (local vessel husbanding department)**, 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 the vessel and the attributes of each transported container are recorded in a special document shared by all participants of the transportation process and 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.

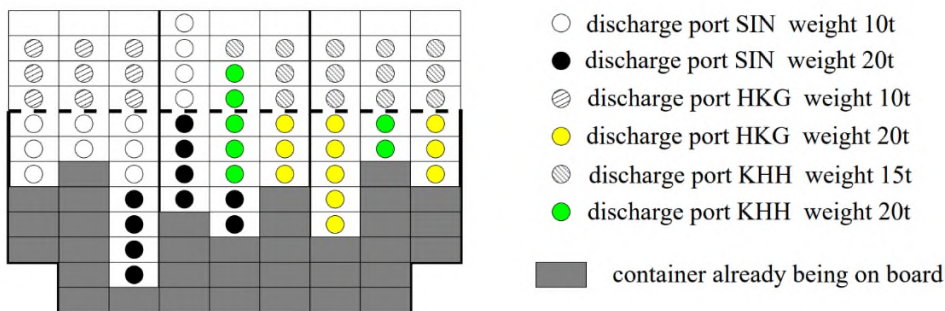


Fig. 2. Example of one bay's cargo plan.

In addition, to simplify discharging, containers bound for discharging at the nearest port preferably should 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.

Special containers introduce their complexity: non-standard, refrigerated, flat tracks, etc. As a consequence, by its nature, the mathematical problem of forming an optimal cargo plan belongs to the class of multi-criteria optimization and has no direct analytic solution. Any practical cargo plan is the result of using many heuristics, and turns out to be not optimal, but only a permissible solution to the problem.

2 Methods and materials: practice of managing commercial vessel loading

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 just static lists reflecting the initial and final state of the cargo on board the vessel during its handling in the 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.

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. 2).

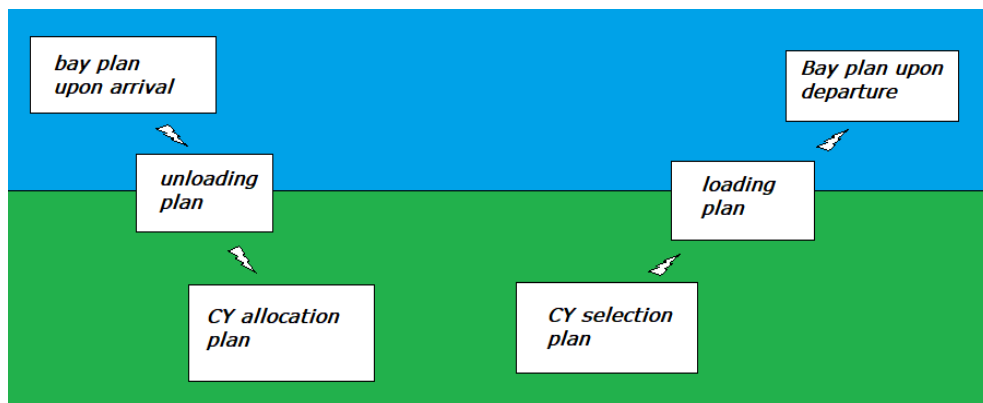


Fig. 3. Operational plans for handling the ship in the port.

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.

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 (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 bay plan 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. 4).

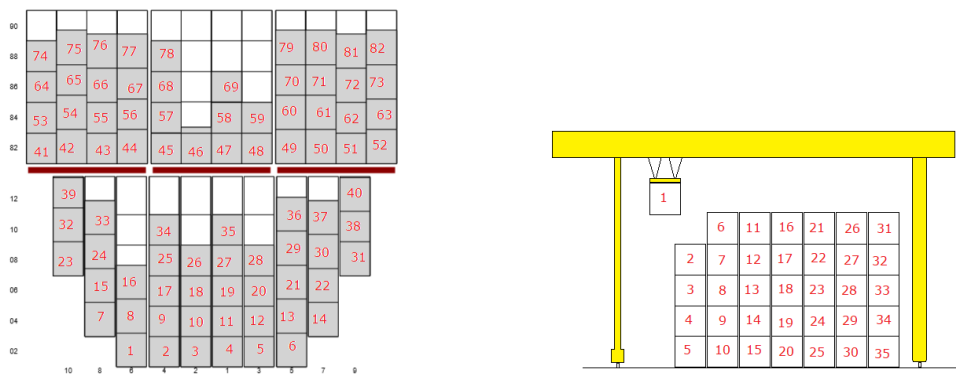


Fig. 4. Stack structure on board the vessel and terminal pre-staking area.

These considerations largely determine the strategy for performing stevedore operations, which is the topic of a separate study.

3 Results: calculation of the time of the ship's stay at the berth

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

$$T_{handl.M} = \frac{2 \cdot D \cdot k}{M_m}$$

where D - container capacity of the vessel, boxes;

k - the capacity utilization factor of a container ship, which is recommended to be taken equal to 0.85;

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

$$M_m = P_l \cdot N_l$$

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 number of lines, N_l	Technical performance, 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

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.

Table 2. Normative reference data from the Technological Design Standards.

Capacity, box	Average No of lines	Technical productivity, 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 container ships' voyages show that several hundred containers from one bay are unloaded and loaded in an average port, and one STS handler is 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.

4 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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