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SIMULATION MODEL FOR CONTROLLING LOADER ACTIONS AT FORMATION AND UNLOADING OF THE OPERATIONAL STACK OF A CONTAINER TERMINAL

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Introduction. In the operational stacks of the container terminal tens of thousands of containers are simultaneously stored waiting for the further actions (technological operations) with them, such as loading onto a vehicle, issuing to the consignee, intra-terminal movements from one process site to another, and performing customs operations mandatory for imported goods [1, 2, 3] and so on. To save the storage area containers are stored in stacks, the permissible tiering of which depends on the technical characteristics of the container loaders used and the permissible loading on the storage area [4, 5, 6]. To reduce vessel downtime under unloading cargo operations the containers can be placed in the storage area by the free space method (in free cells predetermined for them) without taking into account subsequent operations with them which further increases the labor intensity of picking up containers from the operational stack [7] and the total rehandling time during the retrieval process, which is calculated according to the priority of inbound and outbound containers defined by the early retrieval and early loading rule respectively [8].

Tens of thousands of containers are stored simultaneously in the operational stacks of the container terminal waiting for the further processing (technological operations) such as loading onto a vehicle, delivery to the consignee, intra-terminal movements from one technological area to another, performance of customs operations mandatory for imported cargo [1, 2, 3] and so on. Therefore, it is necessary to move them within the terminal from one technological area to another (from the unloading area to the storage area or from the storage area to the loading area on the train, etc.). [4, 5, 6]. These operations are performed by the special transport equipment, for example, different modifications of forklift trucks (frontal with a forked loader, with a retractable crane arm, with a frontal upper or side loader, a portal one) [7, 8]. Advantages of using lift trucks: lack of stationary crane tracks and power supply network; maneuverability and unlimited area of operation; short terms of putting the terminal into operation; simplicity of terminal re-planning and reconstruction. Due to these advantages this equipment (forklifts) is widely used in container terminals in various combinations with crane equipment [9, 10].

To save storage space, containers are stored in stacks, the permissible tiering of which depends on the technical characteristics of the used container forklifts and the permissible load on the storage area [11, 12]. To reduce the demurrage for unloading cargo the containers can be placed in the storage area by the free space method (in free cells predetermined for them) without regard to subsequent operations with them which further increases the labor intensity of removing containers from the operational stack [13] and total rework time during the extraction process which is calculated according to the priority of incoming and outgoing containers defined by the early-extraction and early-loading rule respectively [14, 15].

Methods and materials. Containers that must be taken out at a certain time to perform subsequent technological operations with them, the so-called target containers, are located in certain cells of the stack [4]. Let us set the sequence of coordinates, the location of the container in the stack, as a triple of variables (i, j, k) where i is the coordinate of the longitudinal row, j is the coordinate of the stack tier, k is the coordinate of the transverse row (Fig. 1, a). To perform the picking up operation of the target container, it is necessary to break up the stack [16] containing it (the container), i.e. remove the containers lying on top of the target container (blocking containers). In addition, the stack with the target container, in turn, can be blocked by the stack located in front of it, as shown in Fig. 1, b, for example, a stack from the longitudinal row number 2. In this case, all containers located in the blocking stack must also be previously removed to open access for the loader to the stack with the target container. After removing the target containers from the stack, the containers blocking them must be returned to the stacks they were originally in. All operations for picking up the containers from the operational stack are controlled by a computerized system.

The system is built on the principles of a technological machine operation. As a technological equipment a loader is used, in the particular case, a reach stacker. The actions of the loader when picking up the target containers from the operational stack are controlled from outside using the control program the algorithm of which is implemented in the language of the Mealy deterministic finite automaton, Fig. 2, a – along the longitudinal rows of the stack, Fig. 2, b – picking up the target containers from each longitudinal row [17, 18]. The criteria for choosing the optimal sequence for picking up the declared containers from the stack is the minimum possible number of movements of the loader along the longitudinal rows of the stack (distance criteria).

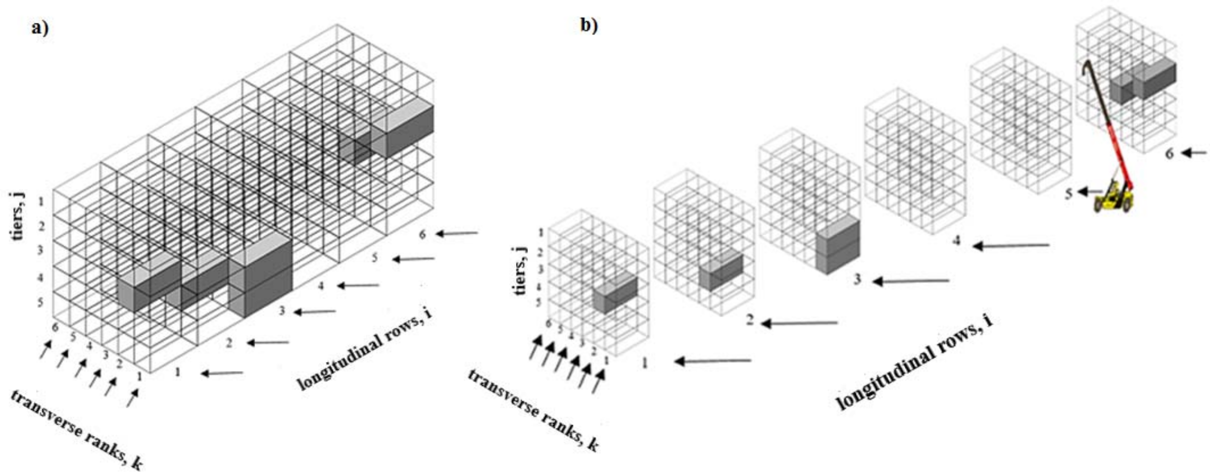
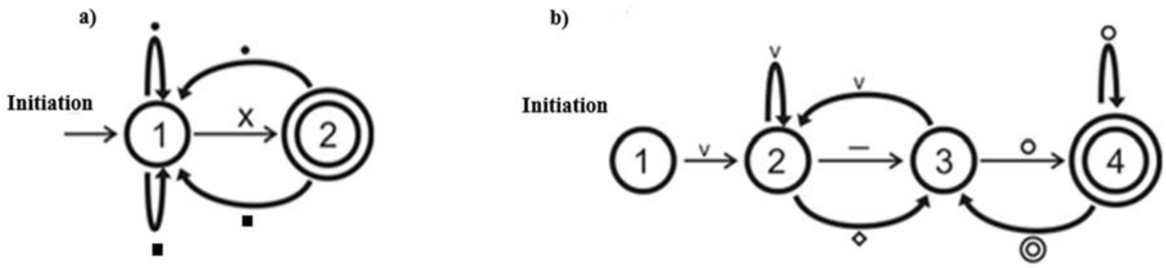


Fig. 1, Operational stack: a) identification of containers location, coordinates (i, j, k); b) example of location of target containers in longitudinal rows



•	Move one row to the right
■	Move one row to the left
×	Stop for picking up containers from the longitudinal row
⊙	Move back one stack

v	Taking out the container
-	Moving the target container to the auxiliary stack
○	Return blocking container to initial stack
◊	Moving one step deeper into the stack

Fig. 2. Diagrams of transitions of the technological machine: a) along the longitudinal rows of the stack; b) picking up the target containers from each longitudinal row

Algorithm for managing the loader actions:

1. An application is received by controlling system which lists the containers to be picked up from the operational stack. For example, there are six of them in the application and their location in the stack is shown in gray (Fig. 1, a).

2. The received application is processed in the database of the container terminal, as a result the location of the target containers in the operational stack is determined, in other words, each container from the application is identified with its location address in the format (i, j, k), where i is the coordinate of the longitudinal row, j is the coordinate of the stack tier, k is the coordinate of the transverse row. The set $Z\{(i, j, k)\}$ is formed. For the example in question the set $Z\{(1, 3, 2); (2, 4, 2); (3, 4, 1); (3, 5, 1); (6, 2, 1); (6, 3, 3)\}$ is used.

3. The current location of the loader is requested from the loader operator through external communication channels. The response to the request is formed as a serial number of the longitudinal row near which the reach stacker is currently located, i.e. i is sent to the control system from an external communication channel – the coordinate from the format (i, j, k) which uniquely determines the initial position both the loader itself near the stack and the initial state q_0 of the control system (Mealy automaton). For the example under consideration (Fig. 1, b) $i = 5$.

4. The serial numbers of the longitudinal rows of the stack are determined from which it is required to pick up the target containers. The first coordinate of the address (i, j, k) of each target container from the set Z points to the ordinal number of the desired longitudinal row. From the set I of all first coordinates of the addresses we make a subset $\{i_0\}$ of non-repeating numbers. The subset $\{i_0\}$ uniquely determines the serial numbers of the longitudinal rows of the stack near which the loader must stop during its movement along the stack in order to perform a sequence of actions to extract the target containers. In other words, we look at the coordinate i in the set $Z\{(1, 3, 2); (2, 4, 2); (3, 4, 1); (3, 5, 1); (6, 2, 1); (6, 3, 3)\}$ and make a subset i_0 of non-repeating numbers of the first address coordinate. The set of first coordinates I $\{1; 2; 3; 3; 6; 6\} \rightarrow \{1; 2; 3; 6\}$.

5. We find the optimal sequence of movements of the loader along the longitudinal rows of the stack, i.e. we rewrite the set of numbers $\{1; 2; 3; 6\}$ in the form of an ordered sequence of technological stops for picking up of target and blocking containers in priority order. For this purpose by using the transition diagram (Fig. 2, a) we generate a set of valid lines that the automaton accepts (Table 1). In table 1 a line of minimum length equal to 10 symbols specifies the optimal sequence of loader movements along the longitudinal rows of the stack (Fig. 3), i.e. the set of numbers $\{1; 2; 3; 6\} \rightarrow \{6; 3; 2; 1\}$.

6. We group the addresses of the target containers according to the principle of belonging to a certain longitudinal range. The first i coordinate in the address (i, j, k) of location of the target container uniquely determines whether it belongs to one or another longitudinal row. The set of addresses Z is divided into non-intersecting subsets along the i coordinate. Thus, subsets $Z_i\{(i, j, k)\}$ of container groups are formed picking up from the longitudinal rows in the sequence of bypassing these rows defined in p.5. For the example under consideration, from the set $Z\{(1, 3, 2); (2, 4, 2); (3, 4, 1); (3, 5, 1); (6, 2, 1); (6, 3, 3)\}$ according to the sequence $\{6; 3; 2; 1\}$ we obtain the following subsets Z_6 $\{(6, 2, 1); (6, 3, 3)\}$, Z_3 $\{(3, 4, 1); (3, 5, 1)\}$, Z_2 $\{(2, 4, 2)\}$, Z_1 $\{(1, 3, 2)\}$.

7. For each of the four subsets Z_i, using the Mealy automaton (transition diagram in Fig. 2, b), lines are generated to control the actions of the loader when picking up the target containers from each longitudinal row. For example, the control line for the sixth row (the set Z_6 $\{(6, 2, 1); (6, 3, 3)\}$) is shown in Table 2. For the remaining sets Z_3 $\{(3, 4, 1); (3, 5, 1)\}$, Z_2 $\{(2, 4, 2)\}$, Z_1 $\{(1, 3, 2)\}$ control lines are generated similarly.

Table 1

Valid line	Length	Stops	Valid line	Length	Stops
•×■■■ × ■ × ■ ×	10	6; 3; 2; 1	■■ × ■ × ■ ×• • • • • • ×	13	3; 2; 1; 6
•×■■■■■ × ■ × ■ ×	12	6; 1; 2; 3	■■■ × ■ ×• •× • • • ×	13	2; 1; 3; 6
•×■■■■ × ■ ×• •×	12	6; 2; 1; 3	■■■■ ×•×•×• • • ×	13	1; 2; 3; 6

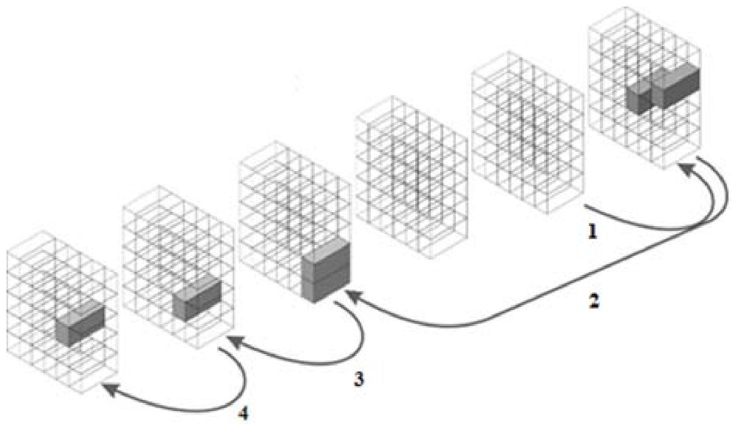


Fig. 3. Sequence of bypassing longitudinal rows when picking up target containers from the stack

Table 2

Control symbols line						
v	v -	v v v	◊	v v v v v v	◊	v v
Taking out the blocking container in the first stack	Taking out and removal of the target container with coordinates (6, 2, 1)	Taking out containers blocking the second stack	Moving the loader one step deeper into the stack	Taking out five containers blocking the third stack	Moving the loader one step deeper into the stack	Taking out blocking containers in the third stack
Control symbols line (continued)						
v -	○ ○	⊙	○ ○ ○ ○ ○	⊙	○ ○ ○ ○	
Taking out and removal of the target container with coordinates (6, 3, 3)	Return blocking containers to the third stack	Moving the loader back one stack	Return blocking containers to the second stack	Moving the loader back one stack	Return blocking containers to the second stack	Work with the sixth longitudinal row is over

Results. As a result of the operation of two Mealy machines (Fig. 2) a line of symbols (signals) was generated that specifies the sequence of movements of the loader along the longitudinal rows of the stack with stops near some of them (highlighted in Table 1 in gray), as well as lines of symbols (signals) specifying the sequence of actions of the loader to pick up containers at each such stop. Together these lines define the sequence of signals for controlling the actions of the loader when taking the target containers from the operational stack of the marine terminal.

The transition diagrams shown in Fig. 2 and the sequences of control signals generated on their basis (Table 2) program the processes occurring in the process automaton control unit. At that, the transition diagrams of the Mealy automat interprets the control logic of the loader's actions when unloading the container from the stack, and each symbol of the control line corresponds to some operation from the work cycle of the loader. In other words, by means of transition diagrams and a sequence of coded SYMBOLS the function of automated control of technological operations of the loader at the mechanized container terminal is implemented.

Summary

The algorithm proposed in the work for controlling the actions of the loader when picking up containers from the temporary storage stack is the basis of the author's computerized control system of cargo transportation and storage operations, developed for a marine container terminal [19].

The method of automat programming was used as a tool for creating a computerized control system which allows creating automated control objects, representing a set of control systems with feedbacks (a system of interacting finite automata) and a control object, i.e. to automate technological processes. The control object in this case is the loader working as a technological automaton of cyclic operation. The control unit is implemented as a transition diagram of a deterministic finite Mealy machine. The technological automaton is connected with the external technological environment of the terminal. Through the information flow which contains information about the location in the stack of containers to be picked up (application accumulator), commands and control signals for the loader, as well as information signals generated by the control unit and carrying information about the state of the finite automaton at a given time.

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