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THE STACK CONTROL STRATEGY BASED ON THE CONCEPT OF OPERATIONAL TEMPERATURE

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Abstract: The paper studies two different types of container strategy: the traditional one, which involves container allocation into positions with a minimum stack height; and the "temperature" one, which considers the positions with a minimum "temperature" for the containers in the stack below. The "temperature" in this case means a metric which is connected to the storage (dwell) time of the containers. Particularly, this value can be represented by container selection probability or number of days stored in the container yard. Utilization of different metrics results in significantly different numbers of moves. Therefore, the authors compare two container stacking strategies: the traditional one and the temperature strategy with different metrics. It is stated that these strategies can be compared only by simulation modelling. The paper describes the main algorithms used to provide simulation modelling. The results of the research show that the temperature strategy with container dwell time as temperature metrics can save 6% of the total moves necessary to maintain the container flow.

Keywords: container stacking strategies, simulation modelling, container yard, container equipment, container terminal, seaport, dry port, container selection, laboriousness, container equipment.

1. STATEMENT OF THE HYPOTHESIS

One of the key decisions related to the improvement in container terminal effectiveness is the introduction of container storage strategies [Borgman, Van Asperen and Dekker 2010; Kuznetsov, Kirichenko and Izotov 2018; Maldonado et al. 2019]. The strategy in this case means an intelligent way of container replacement [Dekker, Voogd and Van Asperen 2007; Kuznetsov et al. 2020]. The container stacking problem is well known in scientific research [Hamdi, Mabrouk and Bourdeaud'huy 2012; Dayama et al. 2017; Gunawardhana, Perera and

Thibbotuwawa 2021]. It has been shown in papers [Kuznetsov, Kirichenko and Semenov 2019, 2020] that different container stacking systems lead to different container selection laboriousness, which in turn requires different amounts of container equipment. The effectiveness of particular strategies can be proved only by simulation modelling [Kuznetsov et al. 2016; 2020].

This paper considers the comparison of two types of strategy: the traditional one, where containers are stacked at the lowest positions; and the "temperature" one, where the containers are placed to position with minimum "temperature". The goal of the paper is to obtain the quantitative gain of new strategy utilization. The main hypothesis of the work is that the "temperature" strategy can reduce the number of moves necessary to handle a certain annual container flow.

Let us assume that a party of V containers arrives at the terminal at an arbitrary discrete moment of time, t_0 (day), and the terminal has information concerning what shares of this amount will be dispatched every day of the party's dwell time, from $t = 1$ to $t = T$, as Figure 1 shows.

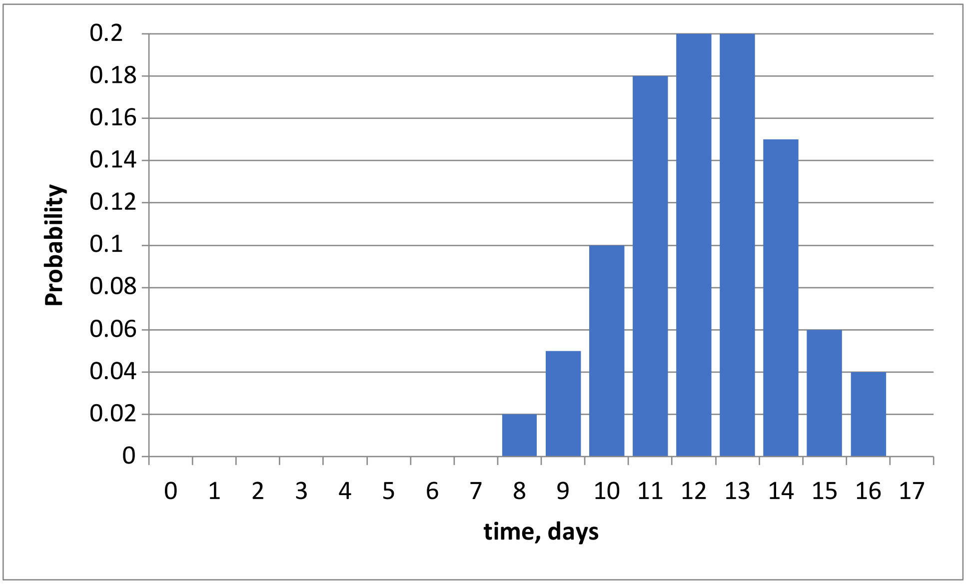

Fig. 1. Rate of the containers dispatch from the terminal

We know that $\sum_{i=1}^{T} f_i = 1$ and that the histogram shown by this figure represents the probability of container selection for a dwell time day, $t = i$. The total share of containers dispatched from the terminal at moment t is:

$$\sum_{i=1}^{t} f_t = F_t$$

In the case of continuous random values, this histogram corresponds to the function of the probability density, $f(t)$, and the relevant integral probability function:

$$F(t) = \int_0^t f(\tau)d\tau$$

This indicates the probability that a certain number of containers has already left the terminal by time t, as Figure 2 shows.

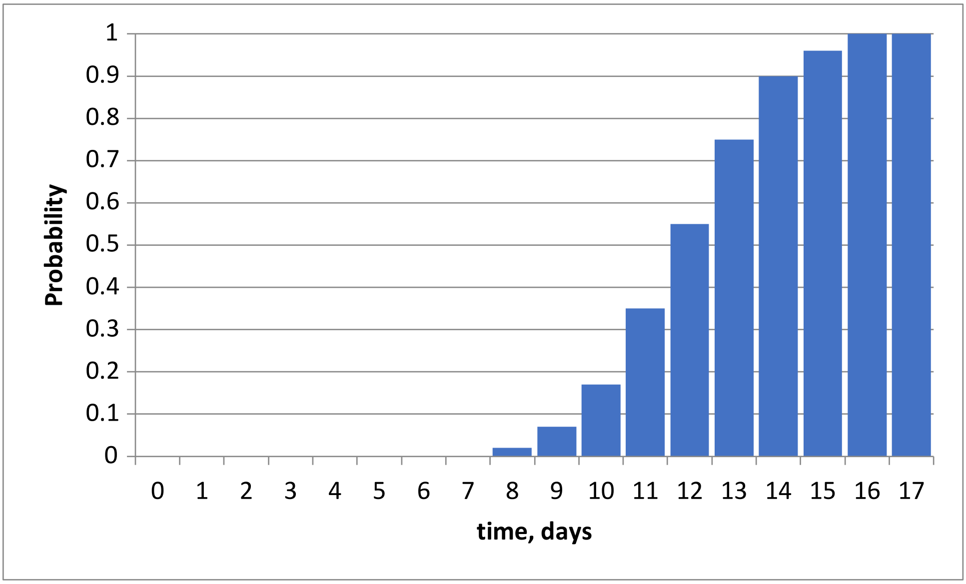

Fig. 2. Probability of the container share having left the terminal

The estimation of the numbers of the party's containers that still dwell at the terminal is given by the function $\overline{F(t)} = 1 - F(t)$. The correspondent discrete value, $\overline{F_t} = 1 - F_t$, is represented by Figure 3.

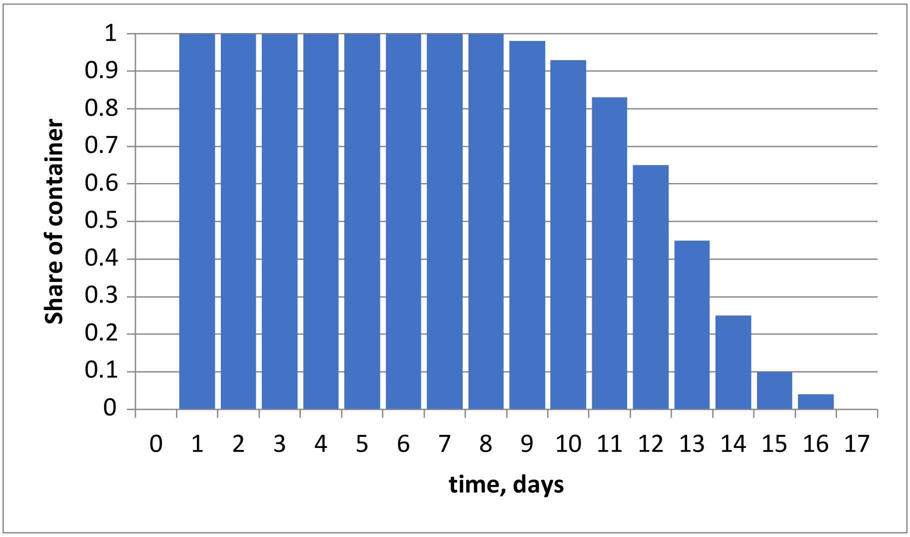

Fig. 3. Share of containers that still dwell at the terminal

The histogram in Figure 1 shows how many containers will leave the terminal on a certain day, while the histogram in Figure 3 gives the amount that is still there. Accordingly, the probability for a given container from the party to be selected at a certain moment of time is $p(t) = \frac{f(t)}{1-F(t)}$ or $p_t = \frac{f_t}{1-F_t}$ for the discrete case. The correspondent histogram is represented by Figure 4.

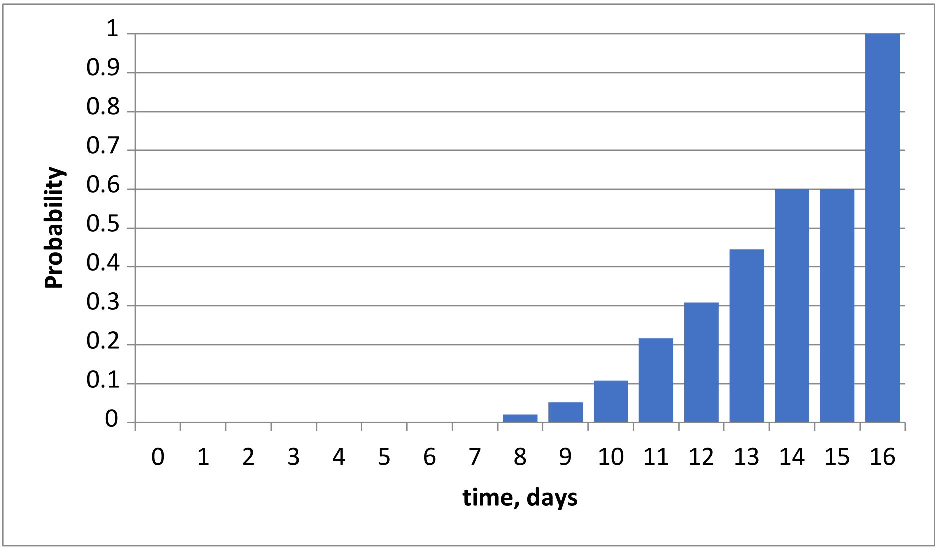

Fig. 4. Probability of a container selection

Indeed, in addressing the combinatorial definition of probability we note that the number of favorable outcomes of the statistical experiments in this case is $k = f(t)$, while the total number of possible outcomes is $N = 1 - F(t)$, so the probability of a certain container selection in this day is $p_n(t) = \frac{k}{N}$.

Strictly mathematically, this probability is defined as the ratio between number of combinations on how to select the rest of containers, C_{N-1}^{k-1}, to the total number of combinations, C_N^k, or $p_n(t) = \frac{C_{N-1}^{k-1}}{C_N^k}$. The transformation below proves the correctness of the consideration above.

$$\frac{C_{N-1}^{k-1}}{C_N^k} = \frac{\frac{(N-1)!}{(k-1)! \cdot (N-1-k+1)!}}{\frac{N!}{k! \cdot (N-k)!}} = \frac{\frac{(N-1)!}{(k-1)! \cdot (N-k)!}}{\frac{N!}{k! \cdot (N-k)!}} = \frac{(N-1)! \cdot k!}{(k-1)! \cdot N!} = \frac{k}{N}$$

The value given by Figure 1 is calculated from the moment when the party arrives at the terminal, t_0, so the absolute time is connected to local time as $t = t_{abs} - t_0$. Consequently, the local time for a party which arrived at a different moment will also be different.

The practice of container terminal traditionally distinguishes between the ‘hot’ containers that should be selected soon from the stack, and ‘cold’ ones that will dwell in the stack for some time. The consideration above offers a natural and objective metric for this intuitive concept of ‘operational temperature’. The derived probability is directly connected to the relevance of the containers by a given moment of time. This value, as Figure 4 shows, changes with time and grows monotonously, showing the proximity to the coming moment of dispatch. The advantage of this metric is that it is built totally from the dependency shown by Figure 1, that is usually included in a standard set of statistical data collected by every terminal.

The correspondent strategy using this metric assumes that every arriving or shifted container should be placed on top of a stack having a ground slot with the lowest combined temperature of the containers, since this ‘temperature’ reflects the probability of how soon these containers will be picked. In other words, the advice from the strategy is to avoid a ‘hot’ ground slot.

Accordingly, in order to reduce the total complexity of handling operations, the arriving or shifted container should be placed in a pile having the coldest ground slot. If there are several slots with the same ‘temperature’, the minimal height is to be taken into consideration.

2. EXPERIMENTAL TESTING OF THE HYPOTHESIS

In order to test the hypothesis, it is necessary to calculate the laboriousness of container flow handling under different strategies on absolutely identical container flows since the expected changes can be smaller than the statistical differences caused by the variation on input/output container flow characteristics and the initial state of container yard at the start of the experiments.

One probable variant of the temperature strategy is utilization of container dwell time as the "operational temperature". This value also increases as the time moves closer to the maximum storage time, but its calculation is simpler.

Therefore, it is necessary to test two types of strategy for container yard management: traditional, based on a search for the lowest position in the stack and the "temperature" strategy, which uses different "temperature" metrics.

In order to compare these strategies, the first step included the generation of two sequences of containers, inbound and outbound. The stack was considered initially to be empty. Each list of containers is a task for the simulation model. For each task the program calculated the number of moves required to implement it, thus assessing the complexity of handling.

In order to obtain statistically reliable results, the number of generated tasks should also be high enough. This number is determined by the confidential interval analysis, which is based on a comparison of the variation of the results.

The implementation of the simulation model is based on an arbitrary container stack to which containers are placed and from which the containers are selected. The container stack capacity, E, was calculated by the common formula which connects the average storage time, T_{str}, intervals between the arrivals of the parties, T_{int}, and their sizes:

$$E = V \cdot \frac{T_{str}}{T_{int}}$$

With the container stack area, s (calculated in ground slots), known, then the average operational height is:

$$H = \frac{E}{s}$$

When $H > 1$ the inbound containers will have to be placed on those that are stored in the stack. This will lead to the container shifts to provide access to the intended containers. The new position where a container should be moved is calculated by the unified position search algorithm that uses different metrics to find the "minimal" position. It is obvious that the operational height of the stack (defined by its space) influences the laboriousness of container selection, and this tie should be also investigated.

At each step of the simulation, the container party temperature is common for each container that belongs to it, and could be easily calculated. Therefore, the total temperature of containers stacked upon one terminal ground slot can be calculated.

At the start of the simulation the first party arrives at the terminal and is evenly spread over the slots of the empty stack. This "epithelial" stacking continues for arriving parties until the necessity to select containers arises. From that point, for any step of the simulation, a requirement to pick up a container below the stack surface might appear. This lead requires the removal of any containers that are stacked upon the target ones. Specifically, to find new locations for shifted containers the ground slots temperature is taken into account. Every move of containers changes the landscape of the container stacks; therefore, the allocation of any freshly arrived party will require the undertaking of a search for the lowest ground slot temperature.

3. DESCRIPTION OF THE MODEL USED TO PROVE THE HYPOTHESIZES

In order to prove the soundness of the hypothesis, a dedicated simulation model was developed. The model dealt with 12 container parties and 100 containers arriving at the terminal every six days. The container dwell time is shown in Figure 1, and the resulting temperature represented in Figure 2.

Each container receives a unique identifier with the format "*Nnnn*", where *N* – the sequential number of a container party, and *nnn* – the number of the container in the party. For example, container number 11094 means that this is the 94th container in party number 11.

The daily task for container selection is formed as the generation of random container numbers based on the container storage time's probability function. An example of the daily task for the selection of the first party is represented by Figure 5.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
								0,02	0,05102	0,107527	0,216867	0,307692	0,444444	0,6	0,6	1	
								1053	1090	1011	1019	1071	1032	1086	1100	1027	
								1035	1007	1055	1046	1004	1081	1033	1044	1082	
									1015	1017	1052	1093	1014	1099	1074	1010	
									1031	1070	1043	1097	1012	1078	1021	1072	
									1005	1008	1067	1013	1024	1089	1036		
										1037	1029	1095	1018	1002	1087		
										1079	1085	1091	1042	1066			
										1023	1061	1006	1020	1060			
										1088	1062	1056	1050	1069			
										1048	1059	1096	1064	1083			
											1039	1054	1058	1092			
											1098	1034	1009	1016			
											1030	1045	1047	1051			
											1022	1075	1084	1094			
											1080	1063	1003	1076			
											1049	1025	1026				
											1038	1028	1041				
											1040	1073	1077				
												1057	1065				
												1068	1001				

Fig. 5. Example generation of a daily container selection task

The generated daily task for each party allows the gaining of the total list of container selection tasks for the entire simulation time. An example of this list is represented in Figures 6–7.

1																					
2																					
3																					
4																					
5																					
6																					
7																					
8																					
9	0,02	1053	1035																		
10	0,05102	1090	1007	1015	1031	1005															
11	0,107527	1011	1055	1017	1070	1008	1037	1079	1023	1088	1048										
12	0,216867	1019	1046	1052	1043	1067	1029	1085	1061	1062	1059	1039	1098	1030	1022	1080	1049	1038	1040		
13	0,307692	1071	1004	1093	1097	1013	1095	1091	1006	1056	1096	1054	1034	1045	1075	1063	1025	1028	1073	1057	1068
14	0,444444	1032	1081	1014	1012	1024	1018	1042	1020	1050	1064	1058	1009	1047	1084	1003	1026	1041	1077	1065	1001
15	0,6	1086	1033	1099	1078	1089	1002	1066	1060	1069	1083	1092	1016	1051	1094	1076	0,02	2074	2081		
16	0,6	1100	1044	1074	1021	1036	1087	0,05102	2031	2061	2033	2045	2080								
17	1	1027	1082	1010	1072	0,107527	2088	2046	2069	2010	2017	2090	2022	2008	2055	2003					
18	0,216867	2068	2042	2035	2034	2052	2070	2018	2093	2085	2062	2004	2014	2072	2007	2082	2094	2029	2086		
19	0,307692	2049	2073	2019	2026	2051	2098	2100	2039	2067	2057	2060	2091	2001	2071	2095	2066	2023	2011	2006	2043
20	0,444444	2053	2050	2037	2065	2015	2024	2005	2099	2056	2059	2075	2025	2076	2092	2036	2032	2009	2016	2078	2058
21	0,6	2028	2047	2021	2038	2030	2079	2040	2096	2002	2020	2089	2012	2064	2097	2054	0,02	3096	3061		
22	0,6	2087	2083	2013	2084	2048	2044	0,05102	3072	3056	3080	3025	3007								
23	1	2063	2041	2077	2027	0,107527	3093	3078	3099	3039	3036	3071	3043	3052	3054	3076					
24	0,216867	3002	3048	3057	3029	3082	3038	3053	3081	3017	3094	3073	3086	3070	3024	3079	3044	3012	3049		
25	0,307692	3023	3035	3060	3003	3018	3063	3032	3091	3045	3008	3055	3014	3090	3087	3098	3084	3064	3068	3085	3022
26	0,444444	3088	3020	3058	3065	3067	3010	3075	3040	3050	3092	3074	3100	3004	3033	3069	3062	3034	3089	3066	3037
27	0,6	3041	3005	3059	3001	3013	3011	3028	3031	3019	3021	3077	3015	3030	3095	3083	0,02	4042	4027		
28	0,6	3026	3016	3042	3006	3027	3051	0,05102	4092	4089											
29	1	3097	3009	3046	3047	0,107527	4056	4069													
30	0,216867	4052	4035																		
31	0,307692	4058	4094																		

Fig. 6. Total plan for container selection

1053	1090	1011	1019	1071	1032	1086	1100	1027	2068	2049	2053	2028	2087	2063	3002	3023	3088	3041	3026	3097	4052	4058
1035	1007	1055	1046	1004	1081	1033	1044	1082	2042	2073	2050	2047	2083	2041	3048	3035	3020	3005	3016	3009	4035	4094
	1015	1017	1052	1093	1014	1099	1074	1010	2035	2019	2037	2021	2013	2077	3057	3060	3058	3059	3042	3046	4055	4073
	1031	1070	1043	1097	1012	1078	1021	1072	2034	2026	2065	2038	2084	2027	3029	3003	3065	3001	3006	3047	4096	4060
	1005	1008	1067	1013	1024	1089	1036	2088	2052	2051	2015	2030	2048	3093	3082	3018	3067	3013	3027	4056	4039	4074
		1037	1029	1095	1018	1002	1087	2046	2070	2098	2024	2079	2044	3078	3038	3063	3010	3011	3051	4069	4098	4081
		1079	1085	1091	1042	1066	2031	2069	2018	2100	2005	2040	3072	3099	3053	3032	3075	3028	4092	4006	4019	4079
		1023	1061	1006	1020	1060	2061	2010	2093	2039	2099	2096	3056	3039	3081	3091	3040	3031	4089	4022	4008	4018
		1088	1062	1056	1050	1069	2033	2017	2085	2067	2056	2002	3080	3036	3017	3045	3050	3019	4053	4061	4063	4091
		1048	1059	1096	1064	1083	2045	2090	2062	2057	2059	2020	3025	3071	3094	3008	3092	3021	4076	4023	4049	4047
			1039	1054	1058	1092	2080	2022	2004	2060	2075	2089	3007	3043	3073	3055	3074	3077	4067	4014	4064	4026
			1098	1034	1009	1016		2008	2014	2091	2025	2012		3052	3086	3014	3100	3015		4090	4040	4012
			1030	1045	1047	1051		2055	2072	2001	2076	2064		3054	3070	3090	3004	3030		4050	4088	4071
			1022	1075	1084	1094		2003	2007	2071	2092	2097		3076	3024	3087	3033	3095		4005	4001	4038
			1080	1063	1003	1076			2082	2095	2036	2054			3079	3098	3069	3083			4077	4029
			1049	1025	1026	2074			2094	2066	2032	3096			3044	3084	3062	4042			4020	4057
			1038	1028	1041	2081			2029	2023	2009	3061			3012	3064	3034	4027			4016	4003
			1040	1073	1077				2086	2011	2016				3049	3068	3089				4083	4066
				1057	1065					2006	2078					3085	3066					4099
				1068	1001					2043	2058					3022	3037					4013

Daily task

Fig. 7. Daily list of container selection task

A simple analytical algorithm was used to evaluate the container stack dynamics, which is defined by the character of inbound and outbound container flows (Fig. 8).

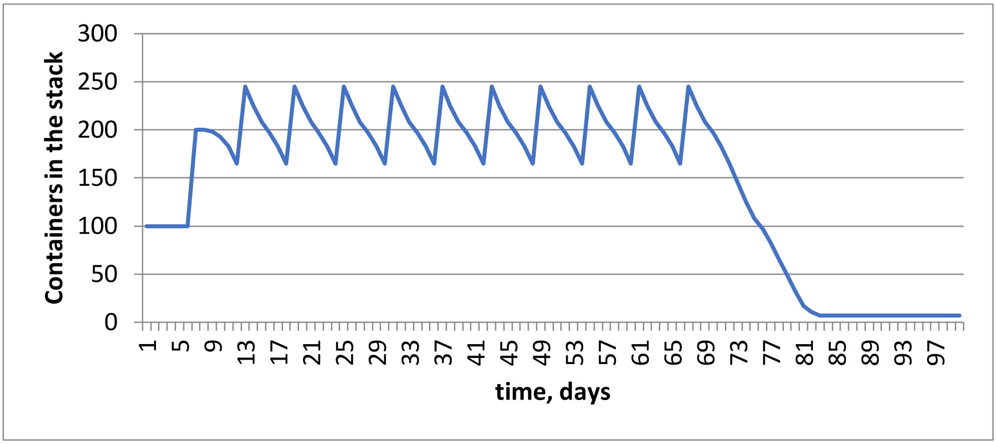

Fig. 8. Dynamics of the number of containers in the stack

As the average number of containers in the stacks was 200, it was decided that the number of ground slots in the stack should be 50. This value provides an average height of the stack $H = \frac{E}{s} = \frac{200}{50} = 4$ tiers.

The simulation included the placement of inbound containers in the stack and their further selection from it in the order set by the generated daily tasks. In some experimental series, the inbound containers were placed in slots with a minimum height, while in others in the slots with minimum temperature. Each movement was registered in the model and used to compare the results.

4. RESULTS

When the containers were placed to the positions having the minimum height, the total number of moves necessary to handle 1200 containers is 3600 (average number of moves on one container was 3). With the containers placed in the positions with minimum temperature, the total number of moves was 3400 (average number of moves was about 2.8).

Consequently, the total gain of utilization of the suggested strategy is 3600-3400 = 200 moves or 6% of the total number of moves needed to handle containers with the traditional strategy. If we suggest that this gain can be scaled, then the "temperature" strategy would require 200,000 moves less than the traditional one (if a terminal's annual container flow is 1,200,000 containers). If the container yard equipment makes 60,000 moves per year, then the suggested technology allows savings of up to $\frac{230{,}000}{60{,}000} \approx 4$ machines or 8 million dollars. These results prove that the suggested strategy allows the reduction of the average number of moves necessary to handle the annual container flow.

5. CONCLUSIONS

1. The laboriousness of container selection can be decreased by utilization of special container stacking strategies.
2. The are several strategies: traditional form, when the containers are located at those positions with a minimum height; and the temperature one, when the containers are placed in a position with the smallest container dwell time.
3. The comparison of these strategies can be done only by simulation modelling.
4. The "temperature" strategy allows the saving of up to 3–4 machines in comparison with the traditional strategy.

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