

Evaluation of Sinking Effect in Container Stack

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ABSTRACT: The container yard is the key element of any modern container terminal. The huge amount of boxes dwelling on the operational areas of the terminals could occupy a lot of space, since one-time storage capacity of the container mega terminal handling over one million TEUs annually is something around 20 000 TEUs. The ecological pressure imposed on modern container terminal does not permit to allocate for this storage large land areas, thus forcing the box stacks grow high. The selection of the individual boxes becomes a complex and time-consuming procedure, demanding a lot of technological resources and deteriorating the service quality. The predicted combinatorial growth of redundant moves needed to clear the access to the individual container is aggravated by the well-known and widely discussed 'sinking effect', when containers arrived earlier are gradually covered by the ones arriving afterwards. While the random selection could be adequately assessed by combinatorial methods, the 'sinking effect' allows neither intuitive consideration, nor any traditional mathematical means. The only practical way to treat this problem today is in simulation, but the simulation itself causes yet another problem: the problem of model adequacy. This study deals with one possible approach to the problem designated to prove its validity and adequacy, without which the simulation has naughtgnoseological value.

1 GENERAL DESCRIPTION OF THE PROBLEM

There is a common opinion that the boxes arriving within a current party cover the boxes that have arrived earlier, thus forcing them to 'sink' to the bottom of the stack. Accordingly, to pick a container one needs to 'dig out' the stack, removing the freshly arrived boxes blocking the access to the designated one. These redundant moves increase the time and labor needed to retrieve the required box [1, 2, 3, 4, 5].

The qualified study of the digging effect needs to distinguish between individual containers arriving and departing in random sequences within separate parties [6, 7, 8, 9]. In order to reveal the inner mechanisms distorting the pure combinatorics we will

start with simple regular case and determined (not random) parameters.

2 COMBINATORIAL APPROACH

Let us assume that the size of one party is $V = 150$ boxes, the dwell time is $T^{dwell} = 8$ days and the interval of arrival is $t = 3$ days. The containers of any party leave the stack evenly, so the dwell time $T^{dwell} = 8$ days means that the last containers of the party would leave in the $T^{disp} = 2 \cdot T^{dwell}$. In other words, the container party dispatch time $T^{disp} = 16$ days, and within this interval $V / (T^{disp} - 1)$ boxes of the party will leave the stack.

During the dwell time of a party there will be T^{dwell}/t other parties arrived and stored in the stack, so the average number of boxes in the stack is $E = V \cdot T^{dwell}/t$. Really, since the interval of arrival of N parties is $t = 365/N$, we could write this expression as $E = V \cdot T^{dwell}/t = V \cdot N \cdot T^{dwell}/365 = Q \cdot T^{dwell}/365$, which gives us the well-known Wilson's formula $E = Q \cdot 365/T^{dwell}$.

In our case, $E = V \cdot T^{dwell}/t = 150 \cdot 8/3 = 400$ boxes. This is the average number of boxes stored in the stack. The arrival of every next party gives a surge that will be evenly sent from the stack within the interval of arrival t . Fig 1 illustrates this dynamics of the container stack.

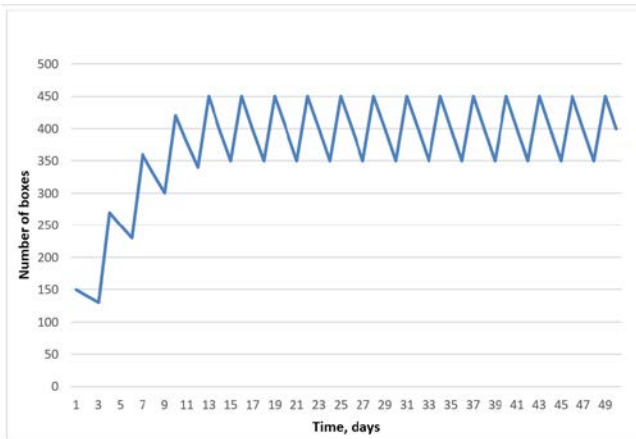


Figure 1. The dynamics of the container stack

The container stack occupies the territory which allows to allocate a limited amount of terminal ground slots (t.g.s.). If the stack foundation measured in t.g.s. is w , then the volume of $E(t)$ boxes forms the stack with the height $h(t) = E(t)/w$, i.e. the dynamics of the stack directly determines its operational height, as Fig. 2 shows.

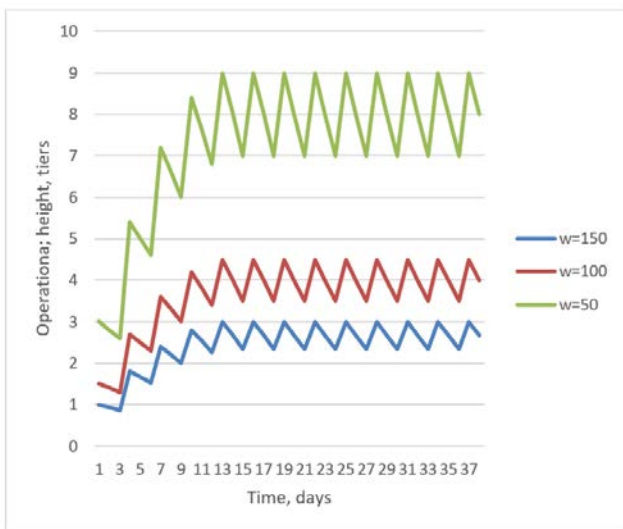


Figure 2. The operational height at different stack area

The combinatorics of the selections could be directly applied to the dynamically changing stack height, since the most related equations include only linear member. The theoretical number of moves per

box calculated for the handling systems with top access by the formula $(h + 1)/2$ is given by Fig. 3.

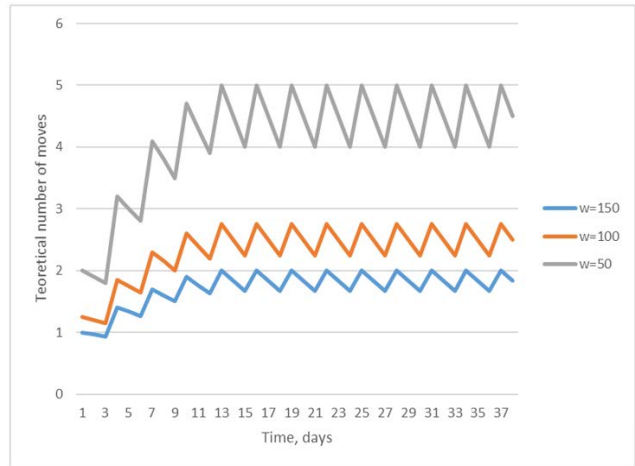


Figure 3. Theoretical number of moves per box

3 BASIC SIMULATION LOGICS

Let us assume that containers from any parties are selected evenly by numbers but randomly by their identification number. The introduction of container identification feature is responsible for the "digging" or "sinking" effect. The only way to estimate this effect is to compare the combinatorial results with those of simulations. In order to be able to reveal all these hidden mechanisms, it is necessary to increase the complexity of the simulation models gradually.

Fig. 4 describes the parameters of the process to be modelled. Each container has a unique identifier formed as concatenation of the party number and its number in the party. For example, 2114 is the box numbered 114 belonging to the party number 2.

Every party of 150 boxes leaves the stack evenly, with 10 boxes abandon it every day. The containers to be selected this particular day form a random sample (10 out of 150, without returning), making it possible to generate a schedule of container selection by days, as Fig. 4 shows.

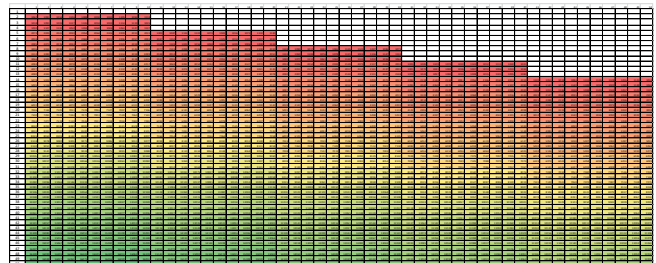


Figure 4. Daily tasks of stack operations

Every strings of this table represents the daily tasks of the stack operations, i.e. the lists of individual boxes from different parties that leave the stack in this day. The order in which these boxes have to be picked is also random, so the elements in every string should be shuffled as a playing card deck.

All the boxes arriving to the stack come into the stack model, all the operation to retrieve boxes are

conducted over this model. The stack model is represented by the rectangular table which reflects the cross-section of the stack: the strings correspond to tiers, the columns refer to t.g.s. in the stack. This is an analogue of the bay-plan in container vessels and container yard layout plans, as Fig. 5 shows.

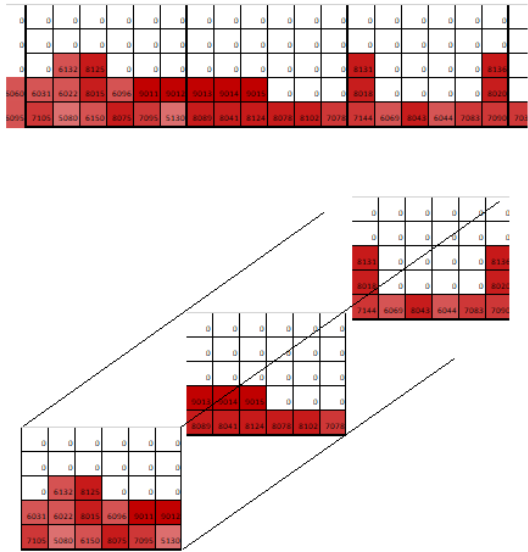


Figure 5. Bay plan of the 3D stack

Fig. 6 shows a beginning stage of the simulation when the first party has already arrived.

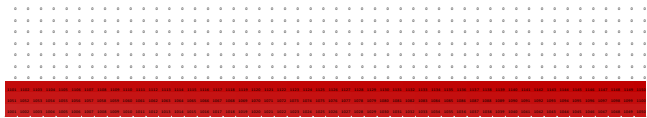


Figure 6. Initial state of the stack

Next stage removes boxes from the stack in accordance with the daily schedule, and place the fresh party on top of the stack surface when it arrives. The boxes on top of the one to be selected are moved into lowest free positions (cells) in the stack. Fig. 7 shows the intermediate stage of the simulation when only two parties dwell in the stack, while Fig. 8 shows a more advanced stage of the simulation.

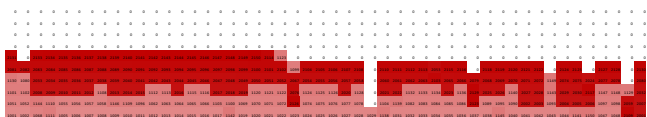


Figure 7. The state of the stack with only two parties dwelling

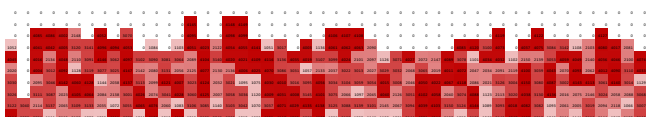


Figure 8. The state of the stack with four parties dwelling

4 RESULTS

The simulation experiments include the shuffling of container parties and selection of the boxes from the stack with different area of blueprint or area measured in t.g.s., i.e. different values of parameter w . In its turn, the value of parameter w determines the operational height of the stack h , responsible for the number of moves per box. The results received in the serial of experiments are represented in Tab. 1.

Table 1. The results of the experiments

w	450	400	350	300	250	200	150	100	50	25
h	0,9	1,0	1,1	1,3	1,6	2,0	2,7	4,0	8,00	16,00
N_{theor}	0,9	1,0	1,1	1,2	1,3	1,5	1,8	2,5	4,5	8,5
N_{sim}	1,0	1,1	1,2	1,4	1,5	1,7	2,0	2,7	4,7	8,7
Difference	0,06	0,12	0,17	0,19	0,19	0,21	0,20	0,21	0,22	0,17

Fig. 9 represents the same results in graphical form.

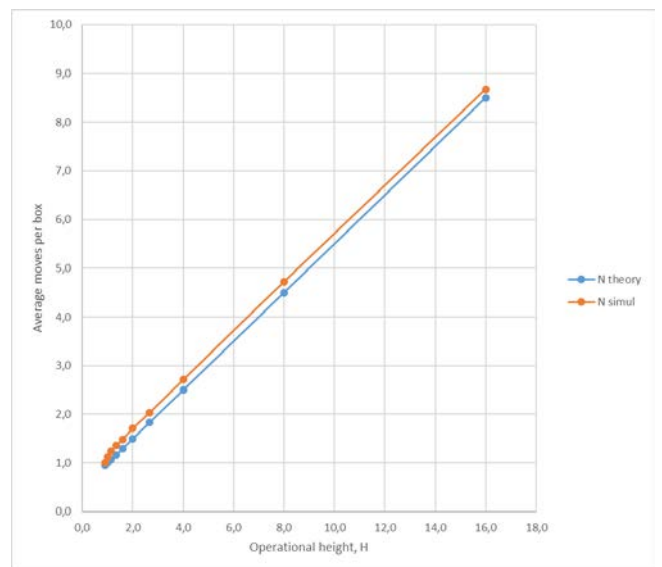


Figure 9. The results of the experiments

These results show that under assumed conditions both the 'sinking effect' and 'digging' of the stack do exist, but they are not significant by the value. This could be explained by the fact that digging of first hot boxes to a great extend re-shuffle the whole stack, thus reestablishing its random combinatorial structure.

Still, this is a conclusion derived from just one sample of the simulation experiment with very simple and regular parameter. Certainly, this hypothesis should be proved by much larger modelling experiments.

5 CONCLUSIONS

- 1 The 'sinking effect' could play a very important negative role in container handling operations, since there are no theoretical instruments to access the size of its influence.
- 2 The representative statistical data to use in its evaluation are very difficult to acquire and reflect to many affecting factors at once, excluding the possibility to separate the one under study.

- 3 The paper offers a regular procedure which introduces a simplified effect of box parties' arrivals and storage on top of each other, that makes it possible to identify the consequences and make numeric assessments by comparison with combinatorial calculations.
- 4 The procedure exploits the simulation model described in the paper and provides rather interesting results which need to discuss with the expert society.

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