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Box Selectivity in Different Container Cargo-handling Systems

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ABSTRACT: The box selectivity in operational stack of container terminal is a quite common and long studied question. The pure random choice is governed by the theory of probability offering some combinatorial estimations. The introduction of operational rules like import/export separation, storage by shipping lines, sorting by rail or truck transportation etc., as well as the most notorious 'sinking' effect, i.e. covering of boxes arrived earlier by next cargo parties – all these blur the clear algebraic picture and lead to appearance of many heuristic outlooks of the problem. A new impetus to this problem in last decades was given by the rapid development of IT, AI and simulation techniques. There are quite many examples of the models described in the scientific publication reflecting many real and arbitrary terminals, which embed very advanced and complicated mechanisms reflecting selected features and strategies. Unfortunately, these models usually are created ad hoc, with some pragmatic objectives and under the demand of closest possible proximity to the simulating objects. There are much less models designated to pure scientific study of the deep inner mechanisms responsible for the primal behavior of the operating container stack, enabling to introduce step by step new rules and restrictions, providing regular proving of every next stage's adequacy and easy to use. This paper describes one attempt of this kind to create a new theoretical tool to put into the regular toolkit of the container terminal designer. The study starts with mathematical (combinatorial) considerations, proceeds with some restrictions caused by physical and technological characteristics, and ends up with the simulation model, which adequacy is confirmed by practical results.

1 INTRODUCTION

The given cargo annual throughput of a container terminal Q and the known average container dwell time T^{dwell} enable to estimate one-time storage capacity E needed to store containers: $E = Q \cdot T^{dwell} / 365$. The standard containers provide the possibility to stack them in several tiers, thus reducing the area for their allocation in the container yard, since the area measured in terminal ground slots is $s = E/h$. On the other hand, the higher is the operational height of the stack, the bigger moves needed to select the required box from the stack. Both the area for the stack allocation and extra shuffling moves cause the financial losses, so in order to determine the optimal value of the operational height one needs to find a balance between these costs, as Fig. 1 shows.

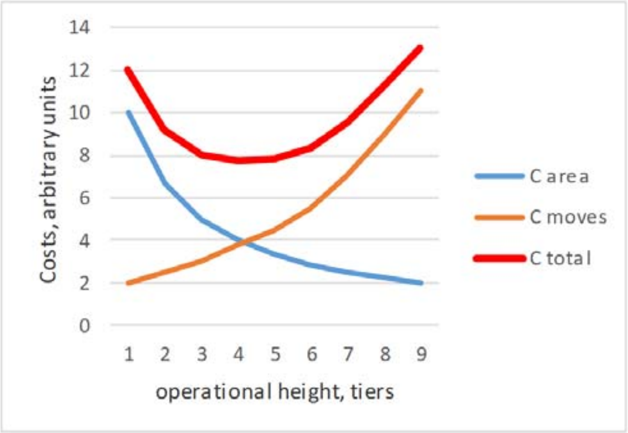


Figure 1. Cost of area against cost of moves in total operational cost.

The assessment of the operational areas needed under different cargo-handling systems and calculation of the relevant costs are relatively well studied, while the question of the selectivity remains vague [1, 2, 3]. This paper inputs some considerations to this domain.

2 CONTAINER SELECTIVITY

The selectivity is usually defined as the ratio between the number of commercial (productive) moves to the total number of moves, productive and non-productive [4, 5, 6]. Since for one container there is only one productive move which brings money for the terminal operator, this definition could be written like

$$\text{Selectivity: } s = \frac{1}{N^{move}}$$

The containers needed to be selected (usually referred to as ‘hot’ ones) dwell somewhere in the body of the stack, covered by some ‘cold’ boxes blocking the direct access. Different container handling systems (or, more exactly, the operational features of the equipment used in these systems) need to shuffle either only one ‘column’ containing the required box, or ‘dig out’ through some ajar space in the stack, as Fig. 2 illustrates.

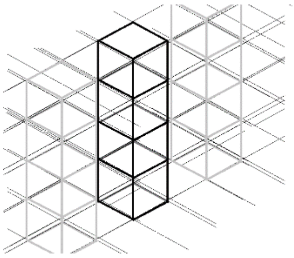
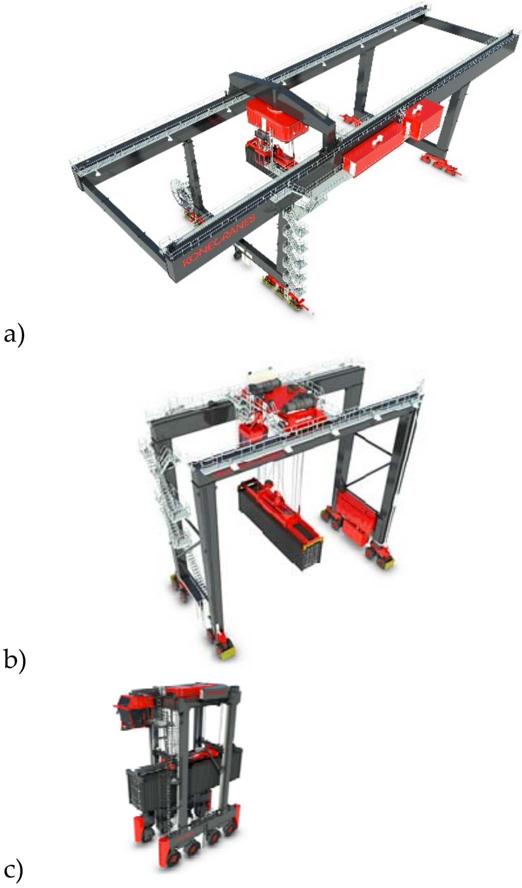
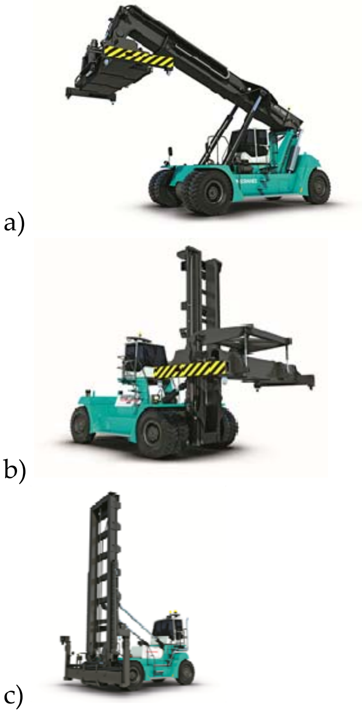


Figure 2. The operational zone for selection

The selectivity in these systems differs greatly. The way how equipment accesses the boxes in the stack divides all container handling systems in two main categories: with top accesses (Rail Mounted Gantry, Rubber Tyred Gantry, Straddle Carrier) and with side access (Front Loader, Side Loader, Reachstacker). The former systems here we will refer to as the gantry type, the latter – the loader type. Fig. 3 and 4 give a general outlook of these machines.



a) Rail mounted gantry; b) Rubber tyred gantry; c) Straddle carrier
Figure 3. Gantry-type container handling equipment



a) Reachstacker b) Mast front loader c) Empty container handler
Figure 4. Loader-type container handling equipment

Therefore, in the context of this study we would distinguish between only two main types of these machines: providing the top and side accesses for the boxes in the stack (see Fig. 5).

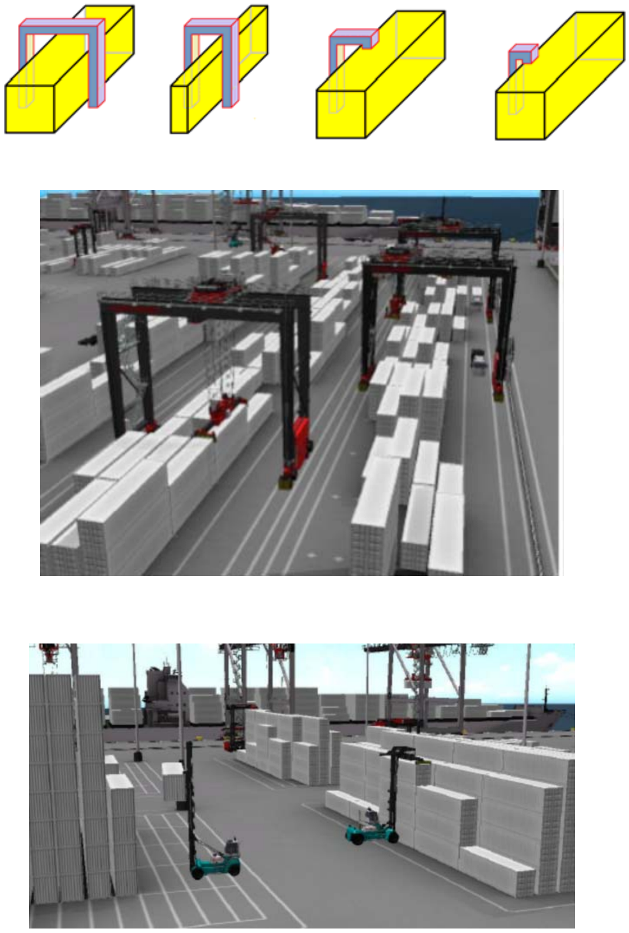


Figure 5. The equipment providing the top and side access to the stack

The first group includes RTG, RMG, SC and ASC, the second - FL, RS, ECHsystems. The top access system we will refer to as gantry type one, the side access system – as front loader system.

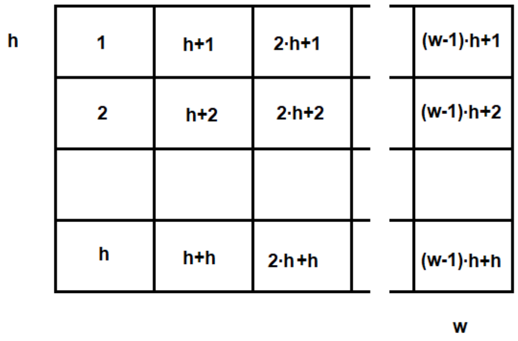
3 THE THEORETICAL SELECTIVITY IN THE GANTRY TYPE SYSTEMS

Let us assume that we have a container stack with the average operational height h. The upper boxes in these systems could be selected in one move, the ones below it – with two moves, the lower boxes – with h moves each. Consequently, the theoretical average number of moves per container would be

$$\boldsymbol{N}_{move}=\frac{1}{2}\cdot(\boldsymbol{h}+1)$$

4 THE THEORETICAL SELECTIVITY IN THE LOADER TYPE SYSTEMS

The loader systems demand to remove not only the boxes on top of the required one, but clear the way through the rows between the machine and column. In case of pure front loader, i.e. with mast forklift trucks and empty container handlers, the number of moves needed to select the box is given by Fig. 6.



1	h+1	2·h+1		(w-1)·h+1
2	h+2	2·h+2		(w-1)·h+2
h	h+h	2·h+h		(w-1)·h+h

Figure 6. The operational zone for selection

Accordingly, the total amount of moves needed to handle the stack with the height of height h tiers and width of w rows is

$$N_w=\frac{(h+1)}{2}\cdot h+\frac{(h+1)}{2}\cdot h+h^2+\frac{(h+1)}{2}\cdot h+2\cdot h^2$$
$$+\ldots+\frac{(h+1)}{2}\cdot h+(w-1)\cdot h^2=\frac{(h+1)\cdot h\cdot w}{2}$$
$$+\left[0+1+\ldots+(\mathrm{w}-1)\right]\cdot h^2$$
$$=\frac{(h+1)\cdot h\cdot w}{2}+\frac{w\cdot(w-1)\cdot h^2}{2}$$
$$=\frac{h^2\cdot w+h^2\cdot w+h^2\cdot w^2-h^2\cdot w}{2}=\frac{h\cdot w\cdot(h\cdot w+1)}{2}$$

Consequently, the average number of moves per container in this case is

$$\boldsymbol{N}_{move}=\frac{1}{2}\cdot(\boldsymbol{h}\cdot\boldsymbol{w}+1)$$

The selection of container in case of the reachstackers needs the total amount of moves in the stack given by the expression

$$N_w=\frac{3}{2}(h+1)\cdot h+(w-3)\cdot\left[3\cdot\frac{1}{2}(h+1)h+h-1\right]$$
$$+\frac{1}{2}\cdot(w-3)\cdot(w-2)\cdot h^2$$

This formula could be deduced from consideration of moves as shown by Fig. 7.

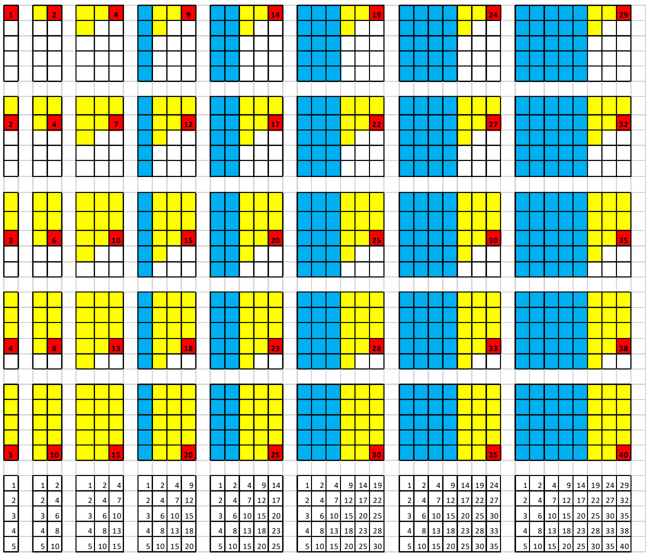


Figure 7. Formula deduction

The average number of moves per container in case of reachstaker is

$$\boldsymbol{N}_{move} = \frac{\boldsymbol{N}_w}{\boldsymbol{h} \cdot \boldsymbol{w}}$$

Fig. 8 shows the comparison of average number of moves per container in different systems.

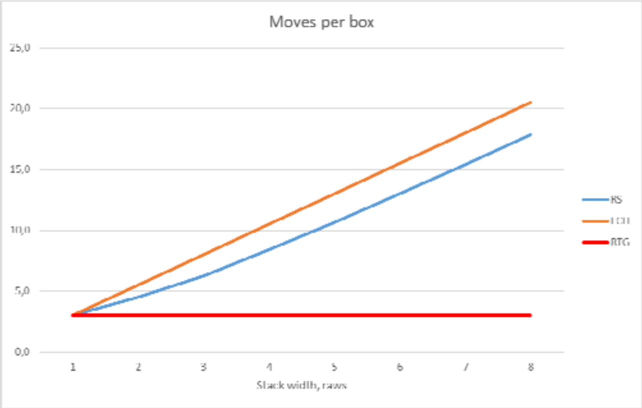


Figure 8. Number of moves in different systems

5 EQUIPMENT PRODUCTIVITY, TECHNICAL AND COMMERCIAL

The primal objective of any cargo-handling systems is in optimal processing of the cargo passing through the terminal. In this respect not the total number of moves needed to access a required box matters, but how many these "productive" moves could be accomplished within the given interval. In other words, we need to assess the productivity in different systems.

Let us assume that an average full cycle of the spreader takes the time T^{move} [sec]. This value usually is reported by the manufacturer of the equipment and enables to calculate its technical productivity

$$P^{theory} = \frac{3600}{T^{move}}.$$

The terminal operator and its clients are interested not in the technical, but in commercial productivity $P^{efficient} = 3600 / (N^{move} \cdot T^{move}) = s \cdot P^{theory}$. This characteristic shows how many client's boxes the equipment could retrieve from the stack in one hour. The working cycles of different equipment differ, with some typical values as $T^{move} = 250$ sec for front loaders and $T^{move} = 120$ sec for gantry type equipment, provide the possibility to calculate the commercial productivity of different equipment. Fig. 9 shows the results of these calculations based on the above-studied selectivity and typical working cycles.

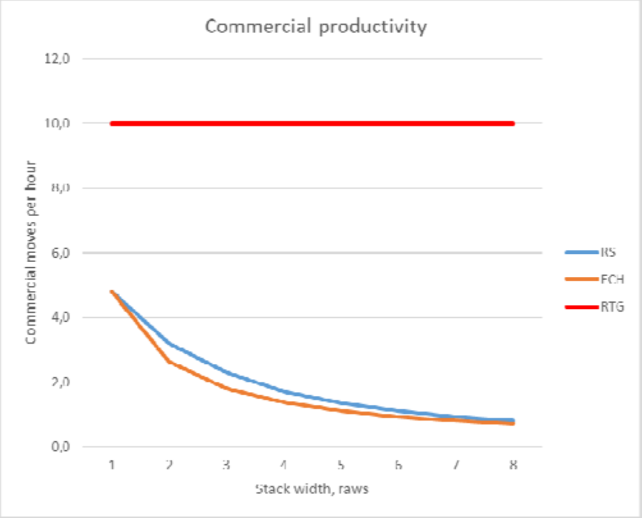


Figure 9. Commercial productivity in different systems

As one can see at this figure, the commercial productivity of front loaders drops dramatically with the increase of the operational height. This explains why the stack width in these systems is limited by 2-4 rows only (with the access from both sides) if the boxes are treated individual and not anonymous. Another point to notice is the convergence of all front-loaders productivity: to clear the access one needs to remove increasing number of vertical rows, with the difference of moves only in the last one.

Usually it is not a problem to assess the cost of operational hour for any cargo handling equipment. Having these done, it is possible to estimate the self-cost of one commercial move in different systems. Provided that the cost of operational hour is given by Fig. 10, the correspondent self-cost of one moves is represented by Fig. 11.

Equipment		RS	RTG	ECH
C hour	**USD/motor-h**	**21**	**24**	**18**

Figure 9. Typical cost of one motor-hour for different equipment

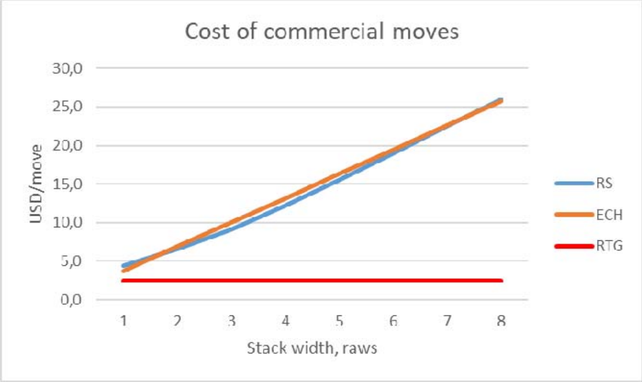


Figure 10. Self-costs of commercial moves in different systems

In the beginning, with low average height of the stack, the reachstacker as the handling machine is better due to its ability to work over the first raw of boxes, but further on this advantage deteriorates due to the higher operational cost of one hour and nearly the same amount of moves.

The study above assumes the pure stochastic mechanism of box selection from the stack. The specialists in container business are aware of the unpleasant fact that 'hot boxes' needed for selection tend to 'sink' to the bottom of the stack being covered by 'cold boxes' arriving later and expected to dwell in the stack for some time. This labor-added mechanism is to be studied in the next paper.

6 CONCLUSIONS

1 In many cases the complex behavior of big systems is the result of big collection of simple but interacting processes.
2 The identification and resultative study of these mechanism require the regular methodological approach from simple to complex perception.
3 The problem of the box selectivity is well recognized and studied, but the results of these researches cannot be acknowledged as complete and final.
4 The paper deals with the most primal mathematical mechanisms responsible for the selectivity of boxes from the stack, taking into account specific features of generalized cargo handling systems.
5 The study ends up with simple formula which can be used for practical purposes and theoretical studies of container operations.
6 The labor-added mechanism is not taken into account here, as well as the procedure of putting boxes into stack.

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