Intelligent stacking as way out of congested yards? Part 2

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Part 1 of this article was originally published in edition 31 of Port Technology International. It is available for download at www.porttechnology.org under journal archives. Part 2 will cover a simulation model, the results and conclusions.

Abstract for Parts 1 and 2

Container terminals are struggling with the ever-increasing volumes, and are therefore searching for solutions to increase throughput capacity without expanding their physical footprint. One way is changing the stacking system itself. Another way is to increase yard density, however this typically leads to a productivity decline when exceeding certain occupancy rates. The question is whether we can avoid this decline by increasing the intelligence of the grounding algorithms? Or do we need additional housekeeping for grooming up the yard? Traditional stack strategies allow for up to 60-65 per cent operational yard density, but here we are looking for achieving 85 per cent and still working at acceptable productivity levels. In this paper, we present an approach how to develop stacking strategies that can cope with higher densities without productivity losses. We have prototyped the algorithms in a simulation environment, and tried them out over a long period of time to be able to assess the long-term effects. We show that principles coming from automated stacking systems, as implemented in Rotterdam and Hamburg (so called controlled random stacking), can also be applied in more traditional facilities, such as RTG terminals.

Simulation model

Total terminal model

The simulation model that we have used to model the stacking strategies and assess them is a comprehensive model in the sense that all processes taking place between gate and vessel are depicted at a detailed level. Basically, the model consists of two main components: one representing the Terminal Operating System (TOS) and one representing the physical process that takes place at a terminal. The connection between the two is quite similar to the interfaces that are in place in real operations between TOS and equipment, handhelds, and other communication devices (for instance, pedestals at gate and truck interchange).

TOS simulation

The first main component is the module in the simulation that takes care of most functionality of a typical TOS, i.e. planning, scheduling, grounding, allocation and dispatching in real-time. That means it comprises the work instructions for each piece of equipment based on the plans that result from information such as load/discharge lists, pre-arrival information, gate arrivals, train schedules, shift schedules, and so on. This information may become available at some point in time, i.e. it becomes available in a realistic way, possibly incomplete, or even incorrect. In principle, at a certain point in time, there is no more information available than the real TOS would have.

Having said this, what is the functionality incorporated in the simulated TOS? And how is it structured? There are two axes along which the functionality has been structured. The first axis is the time horizon, which means that the simulated TOS distinguishes planning (time horizon 18-24 hours), scheduling and allocation of equipment and manpower (time horizon 1-8 hours) and dispatching and grounding (in real-time). According to our information, this is quite in line with the way terminals control their operation, supported by a typical TOS. Input to the TOS simulation is the following information:

- Pro forma berth schedule, made actual to the latest information available at a certain moment, including also the required service level to vessels, and the number of quay cranes working on the vessel
- Load lists of vessels, based on the BAPLIE files
- Discharge lists containing information about the next mode of transportation, the PoD, the container weight, eventually the vessel.
- Gate arrivals (eventually prenotifications), including container pickup or delivery information
- Train arrivals, train load lists
- Availability of equipment (yard, transportation) and manpower per shift

Based on this information, the simulated TOS creates the work plans for each point of work during a certain time period (at least a shift ahead). These work instructions include productive and preproductive moves (also called housekeeping, or gantry moves). Of course, as the work at the landside cannot be planned in detail ahead, an estimate is made based on historical data, i.e. the expected number of moves to be executed during the specific time period. The level of detail of the plans is not very high, i.e. the actual piece of equipment in the yard that will perform the specific move is not yet known. To a certain pool of work, a pool of equipment is allocated, for instance 320 housekeeping moves get 4 yard teams, consisting of each 2 RTGs and 5 trucks throughout an eight hour shift (though not necessarily dedicated to this type of work; RTGs may execute productive moves and housekeeping moves during their shift).

During the execution of the work, work is scheduled in advance. The horizon of scheduling differs quite among various handling systems. The minimum amount of scheduled work is a work queue that ensures timely delivery of a container to a certain point of work, in formula:

$$MinWorkQueue = \frac{\mu(delivery\ cycle)}{\mu(delivery\ cycle)} \qquad (1)$$

Here a delivery cycle is defined as the time needed for a terminal truck to bring one container from the stack to the quay crane and return to the stack. The production cycle is defined as the time needed to load one container from the quay in the ship and for the quay crane to return to its original position. As the

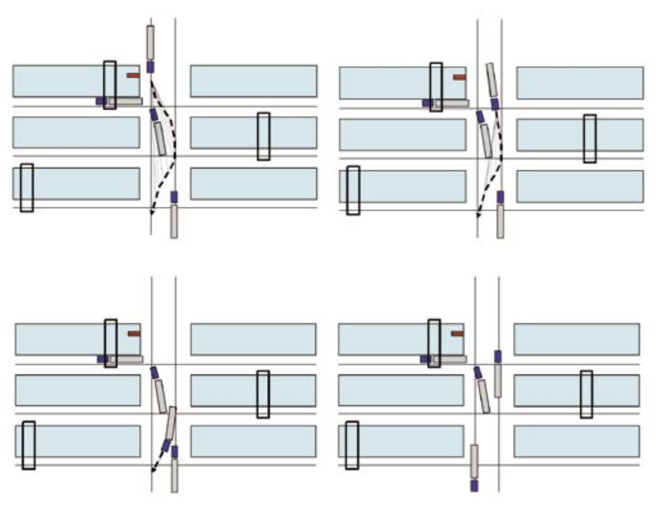

Figure 1. Flexible routing of driving in case of traffic that is in the way.

delivery cycle time and the production cycle time vary a lot, one needs to create a larger work queue to cope with this behavior. The following formula gives a yardstick:

$$MinWorkQueue = \frac{\mu(delivery\ cycle) + \sigma(delivery\ cycle)}{\mu(delivery\ cycle) - \sigma(delivery\ cycle)} \quad (2)$$

Typically, the simulated TOS plans one bay in a vessel ahead per Quay Crane (QC), unless this work comprises less orders than necessary to feed the QC for half an hour with the average rate (so somewhere in between 15 and 25 containers as a minimum). With a typical cycle for a truck of 12 to 15 minutes, the minimum would be 12 minutes / 2 minutes (at a rate of 30 cycles per hour) of 6 moves. Considering delays and faster cycle times, typically a ratio of 20 / 1 results, i.e. 20 orders at least.

The final step in the TOS's work is to decide where a container goes when entering the terminal (water or landside), i.e. the grounding decision, and then to dispatch a specific order (to bring a container from A to B, or to load or unload a container from or to the stack) to a specific piece of container handling equipment. These so called work instructions are handed over to the drivers of the equipment via the said interface. Typically, they appear in the radio data terminals within the cabin of the container handling equipment.

Furthermore, the simulated TOS replans and reschedules whenever there is a reason to do so; this can be a breakdown, but also a serious delay exceeding a certain threshold.

In certain terminals, there may be some freedom of decision for the drivers of RTGs or strads for instance. Instead of receiving individual work instructions, there may be a list of instructions made known to a pool of equipment. It is then up to the driver which job to take from that list. This decision in the simulation is then taken at the execution level, which contains the driver's decision logic.

Simulation of physical processes

The second main component of the simulation model is the part that represents all physical movements, i.e. of container handling equipment and containers. In case of manned equipment, the behavior of drivers has also been modeled, whereas in automated the software that performs routing, collision avoidance, deadlock avoidance, and velocity control is present as well. In the manned situation, the driver takes care of this. In both cases, manned and unmanned, similar types of logic are required, although the way people drive machines, is more flexible, and therefore more difficult to model.

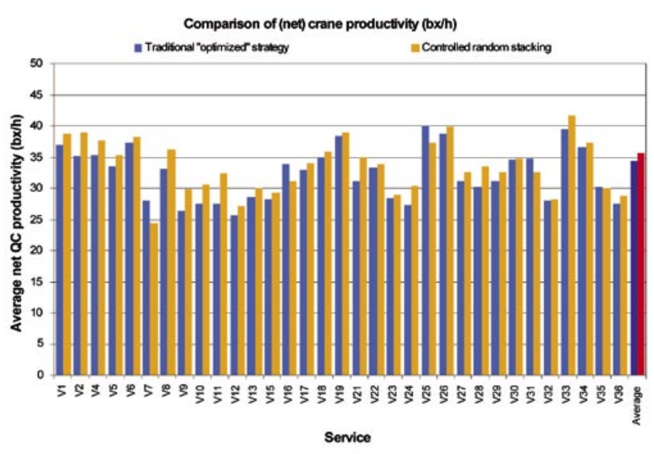

Figure 2. Quay crane productivity measured over all vessel handled in one week for two operating strategies.

In the simulation model, we tried to model the behavior as realistic as possible, i.e. to incorporate all separate movements of machines (gantry, trolley, hoist, spreader) as well as the dead times that typically occur, for instance when picking up a container. Based on extensive measurements at various terminals, observations, and interviews with operational experts, we have come to an equipment model that can be considered to be a valid representation of an average piece of equipment, including an average driver.

Output of the simulation model

The main output of the simulation consists of the following parameters:

- Waterside productivity level in moves per hour (moves/h)
- Landside service time of trucks on the interchange points in minutes
- Equipment productivity on water and landside, respectively of the transportation vehicles in moves per hour (mph), and the RTGs in moves per hour
- The truck handling time at the stack module, measured from arrival until ready to depart

All results will be gathered for various amounts of equipment. More detailed results can be acquired, but are not relevant for the final decision making.

Rules implemented in the simulation

Not all rules that we mentioned are already implemented in the simulation model of the RTG terminal. We started with a very simple implementation of the rules that originate from the RMG terminal, being the following:

- Distribute the containers over the yard, but build piles (one groundslot and the containers on top of that) of containers sailing with the same vessel and for the same port of discharge, and of the same weight class.
- Consolidate real-time by having similar containers attracting each other, which means that piles for the same vessel, for the same port of discharge are likely to be close, Groups of containers for the same service & POD are consolidated and dispersed simultaneously: several locations (stack bays generally speaking) in the yard are used where containers of the same service and POD are grounded together. By doing so, more than one RTG can execute the vessel loading orders – which are likely to be loaded in one vessel bay and hence have to be executed in a small time window – simultaneously. The orders of each RTG will originate from one or a couple of close bays.
- Use the actual workload of the RTG when deciding where to ground a container.
- Use the actual (or better: expected future) position of the RTGs when deciding where to ground a container. If an RTG is near (or approaching) one of the locations where containers of a specific service & POD are stacked, then this area gets priority for grounding. When a new location for containers of a certain service & POD is to be used, then an available location close to an RTG is selected.
- Use expected dwell time of container when deciding a grounding location for the container. In case of relative short dwell time: ground the container closer to the quay, else further away from the quay.

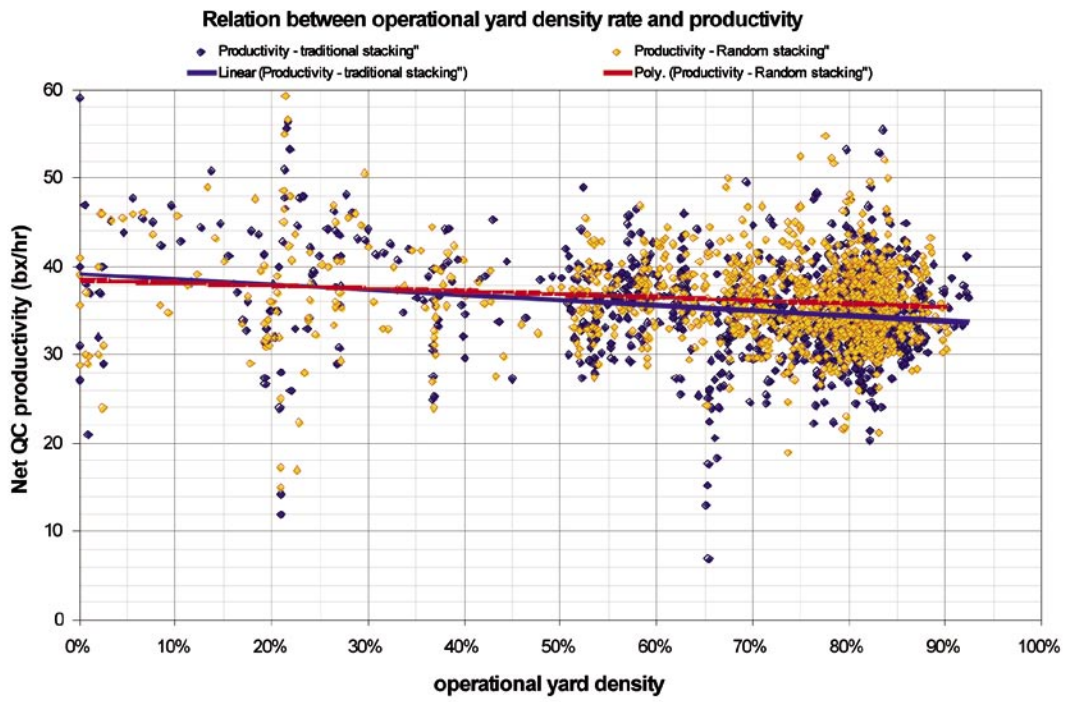

Figure 3. Effect of an increasing occupancy rate on the quay crane performance.

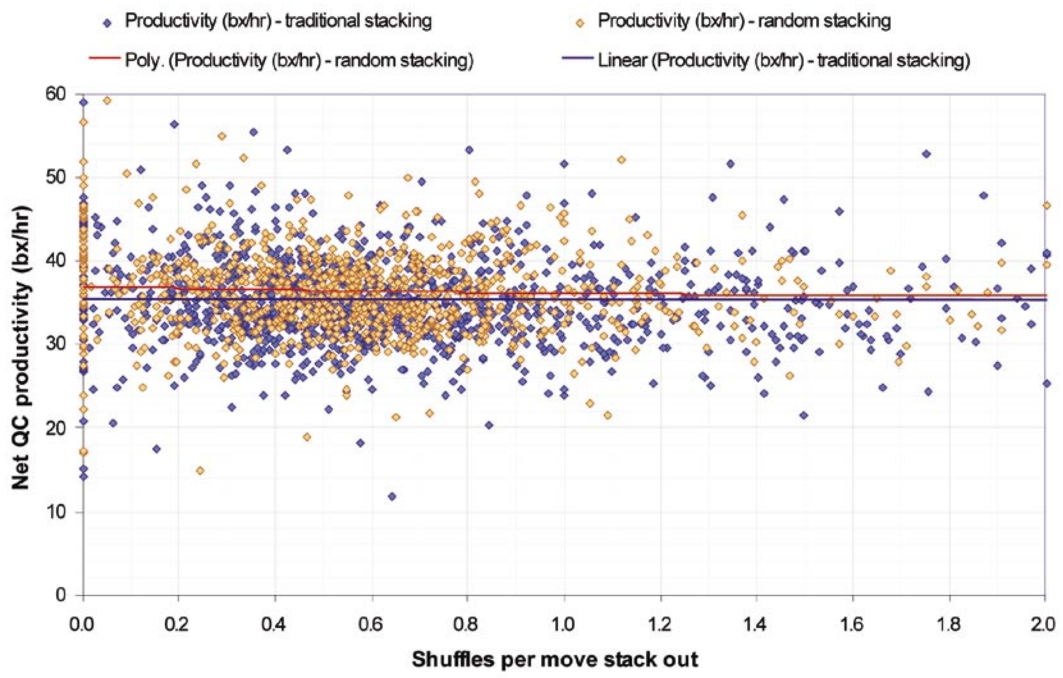

Figure 4. Relation between the number of shuffles per outbound move and quay crane productivity.

- Ground container within range of expected loading vessel when known to reduce truck drive time during loading.
- Ground container close to the quay crane that discharged the container to reduce drive time during discharge.
- Load from the location where the container has been grounded (unless the container has been shuffled).

As a benchmark, we used a fine-tuned strategy especially designed for RTG operation in transshipment mode. Typically the rules as described in part 1 of this article (Port Technology 31) under the section "The first: traditional stacking an RTG operation", are applied.

Results of the simulation experiments

Results simulation of manned RTG terminal

Waterside productivity

The most important performance indicator for a terminal is still the berth and/or the quay crane productivity, although there is a slight increase in interest in performance at the landside. For both analysed strategies, Figure 2 shows the achieved quay crane productivity on each vessel handled in one week of operation.

In the week of peak operation, the yard occupancy rate is around 85 per cent (there is a difference between the traditional strategy where only 5 high was allowed in the area for discharge containers, and 4 high in the loading area; in the random

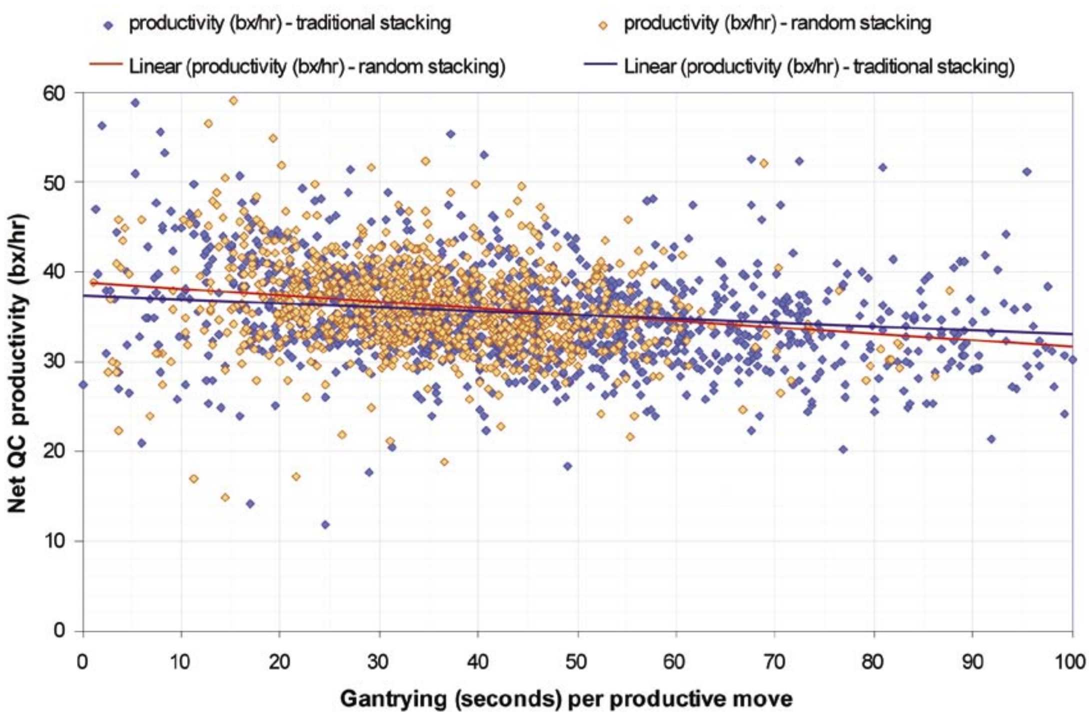

Figure 5. Relation between RTG gantry time per move and quay crane productivity.

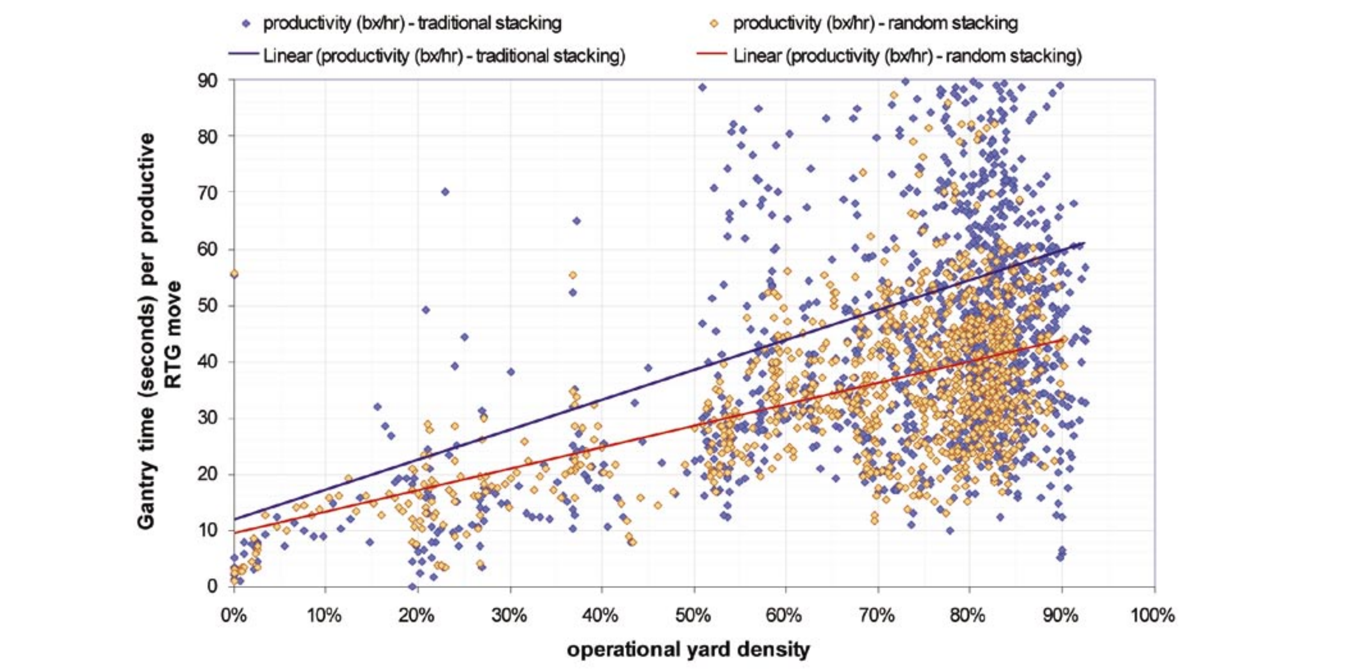

Figure 6. Relation between yard density and RTG gantry time per move.

strategy 5 high was allowed everywhere, herewith decreasing the occupancy rate although the same number of containers were at terminal), measured from the theoretical maximum, i.e. length x width x maximum height. Both strategies deliver an average quay crane performance of approximately 35 containers per hour; the traditional strategy performs about 1 crane move per hour worse over 6 weeks of operation. This means, the vessel turn around time is almost indifferent to these two yard operating strategies.

Another effect which is worthwhile to investigate is the effect of an increasing occupancy rate. During the 6 weeks of simulated operation, the occupancy rate varied between 70 and 90 per cent, which has an impact on the productivity. In both scenarios, the occupancy rate influences performance in a negative way, but the effect is stronger in the traditional strategy (see Figure 3).

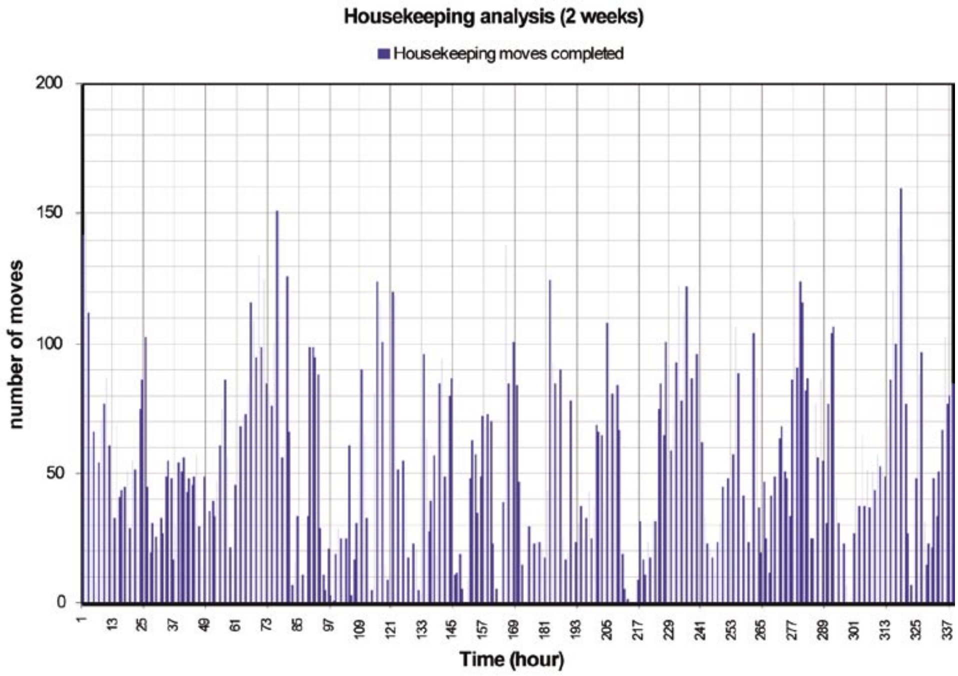

Figure 7. Number of housekeeping moves performed in traditional strategy.

Conclusions

Finding new ways to increase the capacity of a terminal is of imminent importance to the container business, as there are limited alternatives. Therefore, the relevance of increasing the yard density without performance loss, should be clear.

One idea is to apply strategies that allow for higher densities, such as random stacking. As less space needs to be reserved, because all locations are in principle available, the space can be better utilised. This can also be done by refining existing strategies.

In this paper we showed the comparison between a refined, but still traditional, strategy for operating a transshipment RTG terminal with a simple random stacking strategy for this type of terminal.

Overall the difference of the two strategies on performance – here we took the main performance indicator for a transshipment terminal, which is quay crane productivity – is small. Over six weeks of operation, the difference in quay crane productivity was 0.7 container lifts per hour. However, there are some interesting relationships to be observed. First, at an increasing yard density, the productivity decreases.

This is mainly caused by increased movements of RTGs around the yard. Due to the increased gantry movements, the RTG productivity drops, impacting the quay crane productivity to a high extent.

While the impact of density on the gantry movements of RTGs is higher in the random stacking scenario than in the traditional scenario where consolidation of cargo is done, the overall impact of gantrying on productivity is lower, because the terminal is less sensitive to higher yard density with regard to RTG gantrying.

However, since it proves to be a major factor, the refinement of the random strategy should lie in reducing the gantry movements, by trying to consolidate as much as possible, but without reserving any space. Such can be realised by assigning bonus points to storage locations that are close to other storage location where already similar containers are stored. As similar containers are typically loaded at the same time, the RTG will have to move less. However, one should not perform this blindly, as too large contingents of containers may require more than one RTG operating. Then, consolidation at one location leads to RTGs that are hindering each other, which would also lower productivity. Therefore, a next step in our research will be to refine this assignment, taking both effects into account.

References are available upon request.

ABOUT THE AUTHORS

Yvo A. Saanen (MSc in Systems Engineering, PhD on the design and simulation of robotized container terminals, both Delft University of Technology) is Managing Director and founder (1996) of TBA, a leading simulation consultancy company in The Netherlands. He heads the department that supports ports and terminal operators all over the world in their design process of container terminals by means of simulation. During the last eight years, he has carried out over 30 large terminal design projects, ranging from process improvement, terminal extensions, redesign of handling systems, to design of green-field terminals.

He is the main architect behind the TBA port simulation suite (Portalyser) that enables terminal operators, shipping lines and integrators to design, and optimise their terminal and plan their operation in a more efficient way.

Besides Yvo Saanen lectures in different bodies, Delft University of Technology, Institute of Maritime Economics and Logistics, and Lloyd's Maritime Academy about simulation and maritime logistics.

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