

# Intelligent stacking as way out of congested yards? Part 1

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## Introduction

### Pursuit for intensifying yard operations

As container volumes keep increasing, new container terminals are being built and other terminals – in particular those that cannot easily extend their area – aim at increasing the density of the stacking yard. One way is to go for yard handling systems that can put through more containers per square meter, however this is a costly approach for existing facilities; equipment has to be sold or written off, during the transition the terminal has to work half-speed, and cannot handle the regular volume. Therefore, we suggest another approach: higher density stacking without changing the yard handling system in a physical way. We propose to apply stacking rules that can cope with higher densities without a performance decline. Typically, terminals experience problems with stacking containers at operational occupancy rates of 50 per cent or more.

The question is what rules should be applied to accommodate more volume through the same facility, without losing performance. An important issue here is the availability and quality of information about the container flow. Typically, information is late, lacking, or of bad quality. Besides, the information changes over time. This puts one requirement on the set of rules: they have to cope with changing or missing information.

Furthermore, nothing comes for free. It may be that the new set of rules, requires more equipment to be as effective. However, as volumes are going up, costs may also go up in absolute sense, as long as the cost per move stay at the same level, it should be acceptable to the terminal, which forms our second requirement.

Finally, the service level at waterside (serving the vessel) and

landside (serving road trucks and possibly trains) should remain at least at the same level.

### Subject of our exercise

As most container terminals worldwide are using rubber tyred gantries in combination with terminal trucks, we have chosen to apply are stacking strategies to these type of terminals. Typically, the layout of such terminals looks like shown in Figure 1. Behind the berth, there are a number of blocks going into the depth of the terminal. Along the quay wall, these blocks form so called lanes.

In principle there are two types of terminals: transshipment terminals and import-export terminals. The first type mainly moves containers from seagoing vessel to seagoing vessel, whereas import-export terminals move containers from seagoing vessels to hinterland transportation modes, such as barge, trains and trucks. The issues are only partly comparable between the two types of terminals, however, no terminal is strictly the one type nor the other, although there are more and more terminals that are almost 100 per cent transshipment. Examples are Tanjung Pelepas, Singapore, Salalah, Port Said, Gioia Tauro, Malta Freeport, and Algeciras. All of these ports have transshipment rates over 90 per cent. Then, there are many terminals that hardly perform transshipment (typically below 15 per cent), especially in the United States, in England, and at the European continent. However, some of them (for instance Rotterdam and Antwerp) have a high barge share as part of the hinterland transportation modal split. These ports have excellent inland waterway connections deep into the continent. The container flow in those terminals show more characteristics of transshipment terminals than 'real' import-export

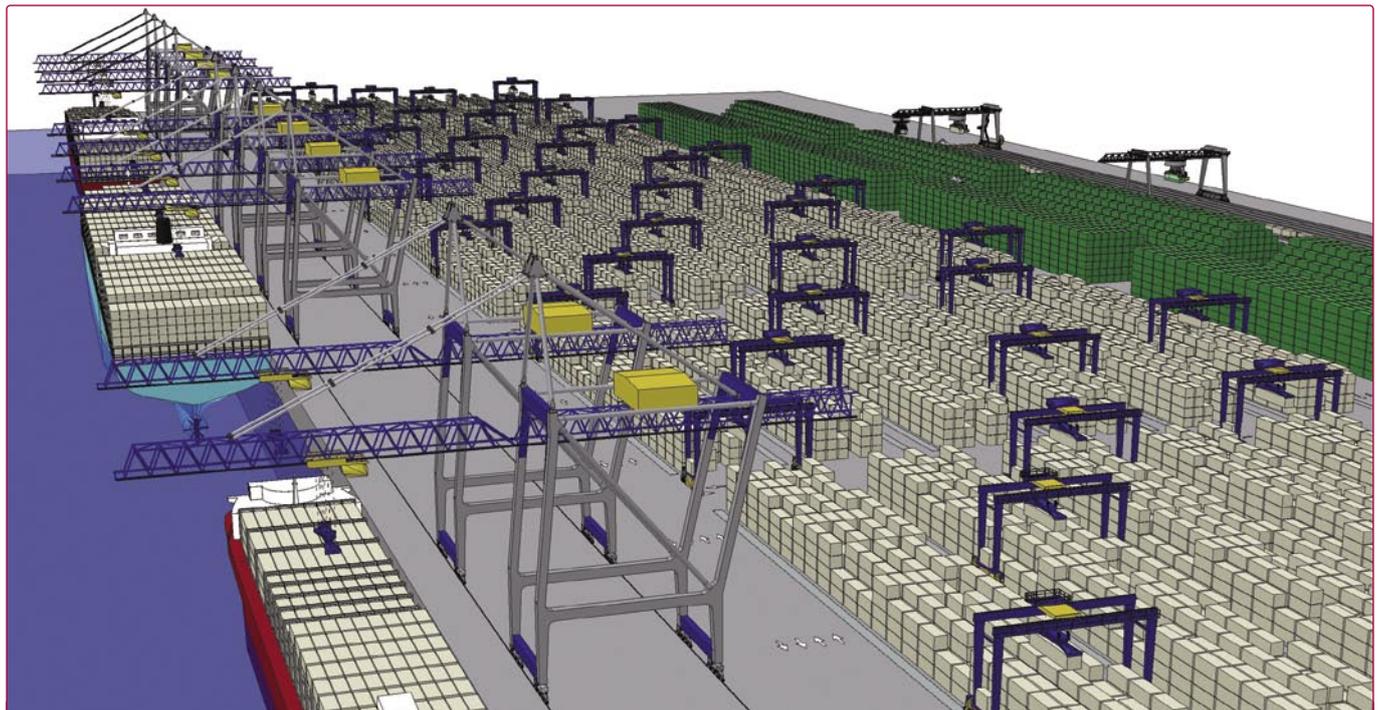


Figure 1. Generic layout for RTG terminal: blocks of containers parallel to the quay, with driving lanes between then blocks for trucks or prime movers.

terminals, because the volume over the quay wall is much higher than handled through gate or rail terminal.

In the reflection, we will discuss what the consequences of these differences are for our conclusions with regard to stacking rules. In the remainder, we will focus on transshipment terminals, as they provide (relatively speaking) the best information about where a container is going. The latter is caused by the extent to which the transportation is organized: hinterland transportation is a poorly organised, scattered processes, with many different suppliers, often one man companies, whereas the sea transportation is more and more in hands of a couple of large shipping lines. Although not perfect at all, the information about seagoing containers is acceptable in terms of availability and quality.

### Methodology of assessment of the stacking rules

In this paper, we try to assess the impact of yard operating rules, as well as we try to define a set of rules that will increase stacking capacity without increase in costs per move, and without a performance decline.

As containers are staying between a couple of hours until a couple of month on the terminal, the consequences of yard operating rules affect the process over a long period of time. Furthermore, the situation at any given moment is subject to dynamic effects. Vessels being delayed, trucks arriving without pre-notice, information coming in late, volumes that vary from vessel to vessel, etc.

These circumstances made us choose for applying simulation as way to assess the qualities of the yard operating rules. This approach has proven to be well suited for the analysis of these kinds of complex systems. Therefore, we have developed a terminal simulation model, containing all operations between the waterfront, and the gate. The waterside transportation is by means of tractor trailers, the landside operation is direct, which means that the RTGs handle the road trucks directly.

### Outline of the paper

The outline of this paper is as follows. First, we will review literature with regard to yard operating rules and high density stacking. Secondly, we will elaborate on the yard operating rules in the reference case and in the alternative case, as suggested by us. Then, we will discuss the used simulation model and the experimental set-up. Subsequently, we will discuss the results of the simulation experiments. Finally, we will discuss the other relevant aspects and come to a conclusion.

## Literature review: high density stacking

A broad range of research has been done on container terminal stack yard operations, in order to improve efficiency. Though, little has been published in scientific literature on stacking problems. A main reason may be that the practical problems are quite complex and do not easily allow for analytical results which are relevant for practice.

Stacking problems can be dealt with in two ways: simplified analytical calculations or detailed simulation studies. The first gives insight into the relationships between the various parameters on a more abstract level. The second can go in much more detail, with the negative by effect that it is time consuming and only few people really understand its ins and outs. No comprehensive stacking theory exist today, and a good stack design not only depends on local space conditions but also on the information characteristics of the ingoing an outgoing flow of containers which may vary from place to place. Examples of both approaches are given below.

Sculli and Hui (1988) were among the first to develop yardsticks for the relation between stacking height, utilisation (or storage space needed) and reshuffles by applying a comprehensive simulation study. Taleb-Ibrahimi et al. (1993) discuss this

relation for export containers both at a longterm scale as well as operationally. They discuss dynamic strategies which store early arriving containers in a rough pile, until a certain date, after which all containers for a ship are put in a dedicated storage area (usually close to the berthing place of the ship). The procedures developed calculate the storage space needed as function of the stacking height. De Castilho and Daganzo (1993) continue these studies with the stacking of import containers. They consider two strategies, one which keeps stacks of the same size versus one which segregates the containers on arrival time. A slightly more detailed discussion resulting in tables and yardsticks (looking at stacking blocks with bays of similar sized containers served gantry cranes), both analytically and by simulation was given by Kim (1997). Kim and Kim (1998) extended these studies by also taking the number of stacking cranes into account. They developed a simple cost model for optimising this number using analytical approximations for the various performance measures. Kozan and Preston (1999) provide a model where storage strategies and container handling schedules are determined in order to minimize berthing time. Therefore they want to minimise the sum of setup times, where setup time is described as the time necessary to remove the containers on top of the desired container.

In case the stowage plan is available some time before the sailing, the containers in the export stack may be remarshalled. This results in an "ideal" stack and thus, less handling work during the loading operation of the vessel. Kim and Bae (1998) describe a two stage approach in order to minimise the number of containers to be moved and to do so in the shortest possible travelling distance. Although such a remarshalling approach seems very attractive, it is not often possible to do so. As already mentioned, the stowage plan is only known shortly before the loading operation. Moreover, building up this 'ideal' stack also requires additional storage space which may not be available.

Segregating space allocation strategies of import containers was studied by Kim and Kim (1999). In segregation strategies, stacking newly arrived containers on top of earlier arrived containers is not allowed. Spaces are thus allocated for each arriving vessel. They study cases with constant, cyclic and varying arrivals of vessels.

An empirical statistical analysis of the actual performance at a Taiwanese container terminal was provided by Chen et al. (2000). The number of shift moves was related to the storage density, the volume of containers loaded and the volume of containers discharged both for stacking crane blocks and straddle carrier blocks.

Decision rules using weight groups for locating export container were derived and validated through dynamic programming by Kim et al. (2000). Weight is a useful criterion since heavy containers are usually stored deep in a ship.

Stacking policies for automated container terminals are investigated by Duinkerken et al. (2001), who use a detailed simulation model that not only models the stack, but also the quay transport in an automated container terminal. They also apply categories, but in a much more simplified way than we do in this paper.

The results for the straddle carrier operated stacks are not always relevant for the stacks with automated stacking cranes, as reserving space is more complex. Though few focus on assessing different automated container terminal design concepts on behalf of their stack yard design. Below, we present a brief overview.

## Yard operating rules

### Generic choices when designing a yard operating strategy

Although container terminals are different in their appearance, container flows and the information around the physical flow can be described in similar terms for any terminal. Therefore, we have defined a set of generic rules that apply for RTG terminals, but certainly also apply for different types of handling systems.

The following conceptual choices have to be made:

- **Dedication of areas versus no dedication:** What is meant by dedication is that a specific area is meant for specific types of containers. For instance, an area for import containers, or an area for containers for vessel XYZ with port of discharge NY. No dedication means that beforehand, no specific areas – apart from the distinction between reefer, MT and dry – are made. Of course, no dedication does not mean that the rules within the TOS software (e.g. allocation filters) cannot contain preferences for import containers close to the gate, in the contrary.
- **Consolidation versus dispersion:** With consolidation is meant that all containers of a specific type (the degree of specification can be varied, from service, down to vessel, down to vessel-PoD specific) have to go to the same area. In the most extreme alternative, all containers for one voyage go to one (large) area. Dispersion is principally the opposite: one tries to distribute containers of the same kind as much as possible over the yard.
- **Housekeeping versus immediate final grounding:** At the moment, many containers are discharged to a certain location and moved afterwards to the final location from which the container is loaded onto the vessel. This in order to increase productivity. However, these housekeeping moves are additional moves that are not strictly necessary. Therefore, an alternative that avoids housekeeping as much as possible would principally reduce the number of moves, and therefore the cost. The other side is that it may require more equipment (yard handling and transportation equipment) during the productive operation (discharge/loading).
- **Discharge or loading optimised grounding:** Without considering the possibility of intermediary housekeeping, a grounding location can be sought based on the optimal location from a

discharge perspective or from a loading perspective. Especially the distance to the QC is here relevant. The compromise in between is considering both.

#### The first: traditional stacking an RTG operation

When analysing stacking strategies applied at RTG terminals, we need to make a distinction between transshipment terminals and import-export operations. As said earlier, we will focus on the first. So what is said here may or may not apply for import-export operations.

In a transshipment operation, the available information is for 50% of the containers better than in an import-export terminal, because most containers (if not all) are seagoing after arriving at the terminal. The information about where they go and with which ship is known upon arrival to a certain extent – however practice still shows that during the container dwell in the yard 30-40% of the information changes. This makes it possible to locate containers of similar destination (vessel voyage destination) close together in the yard in order to increase the speed of the loading operation, i.e. choice one is consolidation. This can be done in realtime (building in a preference to stack containers next to a similar one, or on top of a same one), or ahead (during the planning process, to be discussed in more detail in part 2). To our knowledge most terminals plan this ahead by allocation areas to specific containers, i.e. they apply a dedication strategy. With regard to the third choice, terminals tend to apply either a mixture between immediate grounding and housekeeping. The degree to which they are able to either one, depends on the quality of information, the timeliness of information, and the amount of equipment available and the cost of labour. The cheaper the labour, the more the focus will be on housekeeping, as the costs are low, and the productivity during vessel operation

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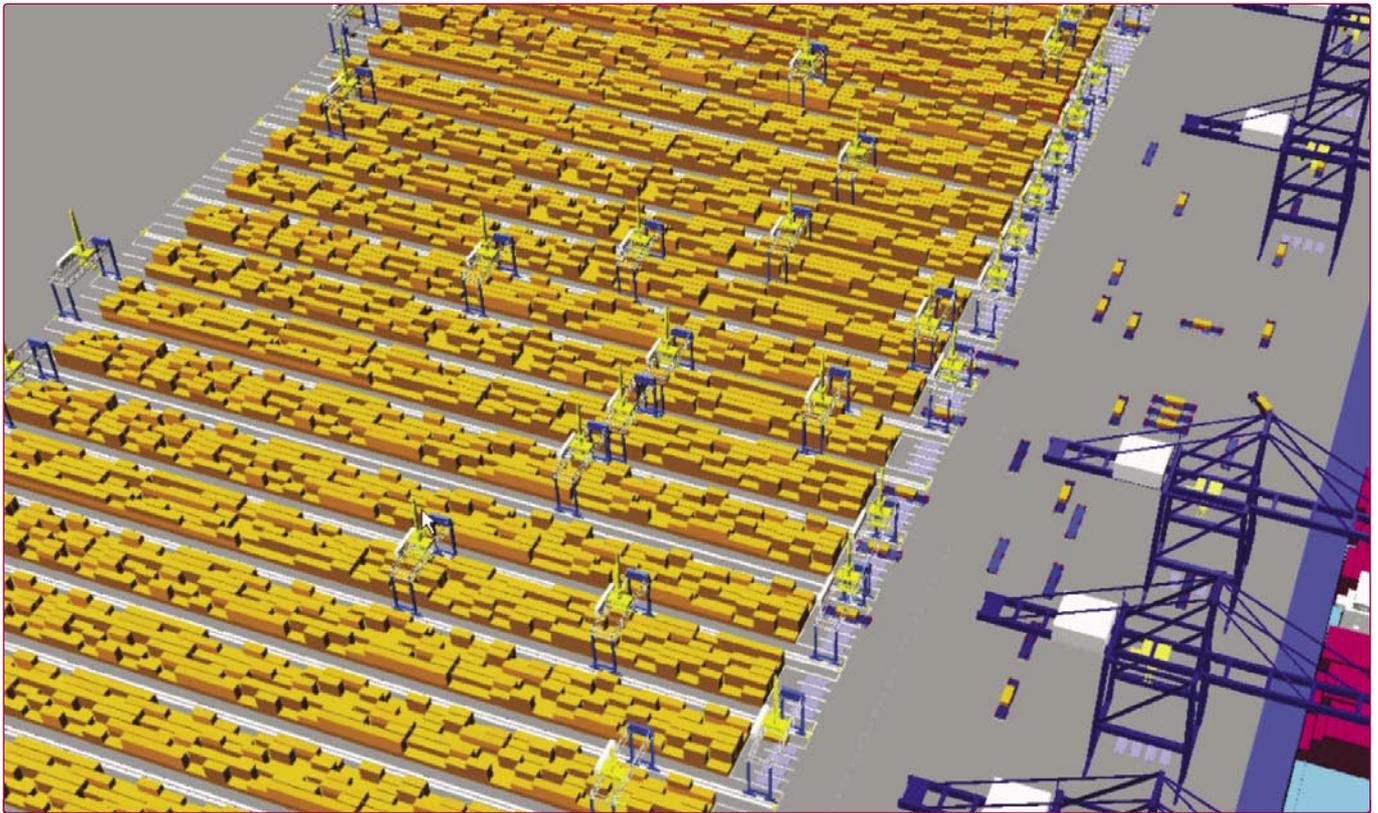


Figure 2. Example of an RMG terminal with perpendicular stack module equipped with one or two (as depicted) RMGs per module.

is higher. The final choice is of lesser importance in the case that housekeeping is inexpensive; if not, it depends on the density of the operation whether discharging or loading is favoured.

#### Typical stacking strategy in an (automated) RMG operation

An operation in a (semi) automated terminal can be quite different from an operation in a terminal where there is manning on the machines. In the latter case, movements need to be minimised as much as possible, simply because the majority of the costs (50 – 70% in North-West Europe and the United States) is labour related. In an automated terminal, however, moves within the yard for instance, can be executed without interference of labour. Therefore, a basic element in the stacking strategy for these types of terminals is housekeeping, i.e. preparing the yard for upcoming operations.

A second rule in these kind of operations is a result of the fact that all RMGs are always available (except when they are broken down or being maintained of course). In an RTG operation, one tries to reduce the RTG in operation as much as possible. Therefore, the load needs to be consolidated as much as possible to avoid the RTGs driving around. As all RMGs are in operation in an automated operation, all locations in the yard are accessible at any time. Therefore, cargo can be distributed over the yard, in order to distribute the workload over as many machines (RMGs) as possible. So no consolidation, but rather spreading out the load in order to maximize the number of RMGs serving a quay crane.

A third rule is related to the fact that the RMGs tend to be fast in the gantry direction, much faster than RTGs. Therefore, one can put the containers in any position in the stack module perpendicular to the quay. Of course, there should be a tendency to the waterside end for export containers, and a tendency to the landside for import containers (gate and rail), but travelling one container position further in the stack (6.5m) takes about two seconds. So travelling the entire block (varying typically between 30 and 50 TEU, equalling 200 – 300m) takes a maximum of 75 seconds or so. Therefore, not to high a degree determining the performance of the RMGs. This means that one can be flexible in positioning the containers in the yard.

A final rule (but this list is not exhaustive) concerns the importance of workload based grounding and scheduling. Each stack module has to deliver about 10-15 containers per hour at the waterside during a peak operation, and there is only one RMG to perform these moves. In order to smoothen the workload, the actual RMG workload is a very important factor when deciding where a discharge container goes to in realtime.

#### Operating an RTG yard according to the rules applied in an RMG terminal

When we take the basic principles and constraints within an RTG terminal – especially the need to avoid much gantrying by RTGs – and apply ideas from operating an RMG one can think of the following rules. It is important to bare in mind that all rules have to be seen in relation to each other. It is not a sequential decision process, but it is a multi-factor decision making process.

##### Rule 1: Apply a multi-factor grounding decision

A container can be grounded at many locations and – in most cases – there is not one single decisive criterion that determines the grounding location. Therefore, the decision is a multi-criteria decision, considering multiple variables. This is typically the way grounding algorithms, such as available in the most common TOS systems, work when configured properly. However, it may be that one or more of the criteria mentioned below cannot be considered yet in common-off-the-shelf TOS systems.

##### Rule 2: Avoid fixed dedicated areas

Avoid any fixed dedication beforehand. However specify rules that lead to a segregation in the yard. Typically the following rules can be applied:

- Import containers: ground them close to the gate
- Export containers: ground them close to the berth from which they will be loaded
- Export containers: ground them based on their time until departure closer or further from the berth

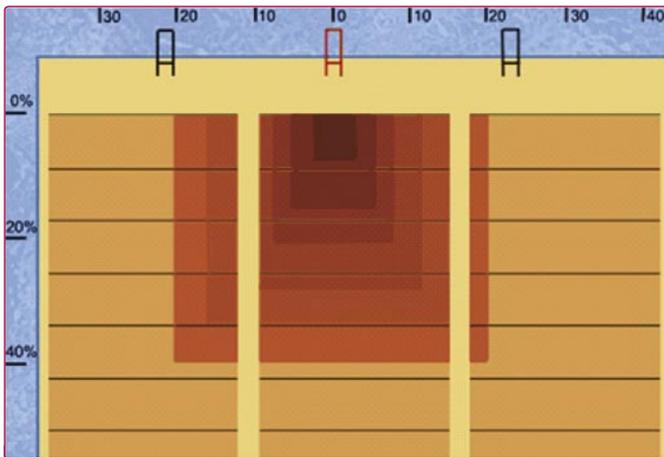


Figure 3. Attraction factor, grounding locations close to the berth of destination are to be preferred during discharge.

### Avoid fixed RTG assignments

In order to allow for a maximum flexibility and a maximum RTG utilisation – typically RTGs produce less than 10 productive moves where it is feasible to operate above 25 productive moves per hour – RTGs should not be assigned to a specific operation during a shift. It may be that due to the consolidation that has been achieved, an RTG is working during a longer period of time for one QC, or one vessel, but generally speaking there is no dedicated assignment.

This will lead to the inability to distinguish between longshoremen (read: waterside operation) and casual workers (read: housekeeping), because those operations will be mixed. As a consequence of the grounding strategy, however, the amount of housekeeping (see rule: avoid housekeeping) will be drastically reduced.

### Consolidate in realtime

Consolidate as much as possible. As said, RTGs do not like gantry travel. Therefore, their productivity rises with a smaller gantry travel percentage. The more similar containers are close to each other, the more productive the RTGs will be, and the less RTGs will be needed to achieve certain productivity. Consolidation starts with building piles (or stacks) of exchangeable containers (same size weight class, VVD). Then as the first pile in a bay is full, it is preferred to stack another pile of the same containers in the same bay or very near.

An additional rule may be to stack containers with a high likelihood of VVD changes, or other reasons for rolling (for instance containers to be loaded on feeder going to West-Africa). When these containers are combined to piles, the number of shuffles per rolling decreases, because the rolling containers do not affect the piles with non-rolling containers, and the other containers in the 'rolling' pile are anyway likely to roll.

### Assign a discharge location as late as possible

Realtime grounding is basically supported by expert decking: a human planner is hardly able to do it without a tremendous effort. Therefore, no earlier than when the container is put on the Terminal Truck, should a discharge location be chosen. This is to avoid any fixed dedicated area.

### Assign discharge locations based on available equipment

A discharge location is only interesting when an RTG is 'near.' Although near is a relative notion, it expresses the principle: by selecting the grounding location in realtime (see assign discharge location as late as possible), a realtime overview of the RTG positions and actual RTG workload, i.e. all orders that are destined or originating from a specific RTG multiplied by the duration per order in the coming 10–15 minutes, have to be considered. The shorter an RTG has to travel, the better it is.

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### Separate consolidated areas for different VVD with same time window

Containers with a different VVD, but with a similar time window should be distributed over different blocks to avoid clashing of RTGs or overloaded RTGs during loading. That means that the realtime grounding should consider the time window upon departure of the container as well. As this information is available in the actual berth schedule, this should be possible. Anyway, as consolidation of similar containers is a rule, and distribution of workload over the various RTGs is a rule, this will in principle happen. However, to ensure it principally, this rule should be added to expert decking.

### Avoid housekeeping (or ground on the final location)

Avoid housekeeping as much as possible, or try to ground on the final location as much as possible. This rule is clearly different from an operation with automated equipment, where housekeeping is almost for free, and direct grounding is sometimes impossible because of a lack of RMG capacity. However, here a housekeeping move costs additional labour hours: it requires three equipment moves (two RTG moves, one truck move). As containers can be stacked anywhere (no fixed areas), containers can be grounded distributed over the yard, based on the availability of equipment at that location, or the availability of similar containers in a non-complete pile (see consolidation rule above).

There are two exceptions when housekeeping is to be preferred over immediate final grounding: 1) a situation is when grounding at the final location is impossible because the required productivity cannot be met due to a lack of equipment or 2) when the grounding in a pre-stack location plus a housekeeping move requires less labour hours than immediate final grounding (for instance in the case of twinlift).

### Use remaining shift hours to housekeep containers

As the workload during a shift is never constant, it is likely that most shifts have some leftover labour hours. In those cases, the available labour is not required to obtain the required productivity levels, and therefore can be used for other purposes. The following housekeeping flows may be initiated then:

- Containers from the 'long dwell time stacks' that are to be loaded (remaining dwell time <7 days) may be moved to the other stacks, closer to the quay.
- Containers that are positioned far from the berth of destination may be relocated, preferably near containers of the same type that are already standing close to the berth of destination.
- Rollings that will cause shuffles during the loading operation that are known at that point in time.
- Containers that are standing in a pre-stack (see rule on avoiding housekeeping).
- Large contingents of containers for different VVDs that are grounded in a single block. As those containers may lead to clashes of RTGs during loading, these containers are candidates for housekeeping.

*End of part 1. So far, the ideas behind a controlled random yard operating strategy have been discussed. Part 2 will cover the results when applying this strategy in the operation. We will discuss the effects on productivity of quay cranes but also of RTGs. Do they really have to move up and down the blocks? Furthermore, we'll review the effects on operating cost, in terms of labour hours, and equipment running hours. From that, we draw our conclusions. Part 2 of this article will be published in edition 32 of Port Technology International. References are available upon request.*

#### ABOUT THE AUTHORS

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