Comparing container storage yards: VCT versus ASC yard

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Abstract—As the volume of container transport increases so do the requirements on handling of containers at terminals. As almost every container on the terminal passes through a storage yard, the storage yard is also forced to increase its performance and storage space. To meet the increasing requirements on the storage yard a company called Polotec designed a warehouse for container storage, the vertical container terminal (VCT). The concept of the VCT aims at storing the containers in a steel structure, therefore the stacking heights is no longer be limited to the maximum height of container stacking nowadays. In this paper the performance of the VCT is evaluated and compared to the performance of an alternative storage yard; a yard with automated stacking cranes (ASC). The results of the experiments show that, although the performance of the used ASC terminal is slightly better than the performance of the VCT, the VCT requires almost 38 percent less space. It is recommended to further research the VCT in different scenarios that more closely resemble the situation on a site where the VCT can actually be applied.

I. INTRODUCTION

Over the past few decades the demand for containerized transport has increased. Container vessels become increasingly larger in size, not only requiring larger equipment to handle the vessel, but also demanding more from the container terminals. Larger vessels result in large call sizes, requiring faster and more handling equipment and larger capacity in the storage yard [1]. The storage yard capacity is limited by the yard equipment, maximum stacking heights and requirements on the performance of the yard in terms of container moves. To overcome these problems the Norwegian company, Polotec designed warehouse for storing containers (Figure 1). Since containers are stored in a steel structure, the containers can be stored higher than currently possible in conventional storage yards. Therefore less space is needed to store the same amount of containers. However, storage capacity is not the only performance indicator for a storage yard. The storage yards should also be able to meet the requirements of the terminal in terms of performance [2]. While a vessel is being loaded or unloaded, the yard should be able to deliver or store containers at a constant flow, to minimize idle time of the quay cranes (QC). The containers have different destinations in terms of modality. Some containers are leaving the terminal per vessel (export) while others leave per truck or train (import). In this paper the performance of the VCT in terms of container moves is investigated by discrete event simulation. The VCT is then compared with an alternative storage yard; an ASC yard with the same storage capacity. The question that is answered in this paper is: How does the VCT compare to an ASC yard in terms of storage capacity and handling capacity? In Section II the design of the VCT is explained in more detail. To evaluate the performance of the VCT, stacking and dispatching strategies are proposed in Section III. In Section IV the characteristics of a typical ASC terminal are described. The ASC terminal is used to compare its performance with the performance of the VCT. The ASC terminal and VCT are compared in the same scenario. The scenario and the results of the experiments are presented in Section V. In Section VI the conclusions of the paper are presented and recommendations for further research are done.

II. VCT TERMINAL CHARACTERISTICS

The VCT storage yard consists of multiple stacks. Each stack consists of several storage floors and a mezzanine floor at the base. When storing a container in a stack, the container is lifted from the ground onto the mezzanine floor by two rail mounted trolley cranes (RMT). The container is moved over the mezzanine floor by the use of roller beds to an elevator in the middle of the stack. The mezzanine floor is presented in Figure 2b. At the left side of the mezzanine floor some unused space is located. This area does not have a specific use, but might be used for storing containers that require special handling. The mezzanine floor does not only move containers from and to the elevator, but also offers the possibility to
temporarily store containers. The arrows in the figure show the direction of movement of the roller beds. The elevator picks-up the container and moves it to a storage floor. At the storage floors so called scissor lift trolleys (ScL) store the container in a slot on the storage floor. Each storage floor has a capacity of 363 40ft containers, which are stored in 18 40ft bays, seven rows and three tiers. The storage floors have two aisles for the ScLs to move along the bays, as can be seen in Figure 2a. To store the container in the VCT the containers need to be locked to the structure of the stack. This is done by placing the container on the so called super skids. These steel frames have retractable pins to lock the skid to the frame of the stack. The super skids are able to carry a single 40ft or two 20ft containers, although the stack currently does not support the process of combining two 20ft containers on the same skid. When a container is stored in the middle, the ScL moves sideways under the containers. When the ScL underneath the correct position of the container, the ScL lifts its platform to either store or retrieve a container from a slot. When a container is stored at the outside of the aisle, the super skid is not locked to the structure, but placed upon a roller bed. Loading and unloading the ScL from these slots is performed by shifting the container sideways onto or from the platform of the ScL. An example of handling a container from both types of slots is also shown in Figure 2a.

III. VCT STACKING & DISPATCHING STRATEGIES

The determination of the optimal location for a container and the job dispatching for the vehicles are considered as two separate parts in the VCT. First the location for a container is determined when a container arrives at the terminal. The dispatching of jobs to the equipment of the VCT depends for the larger part on where the container is located in the yard or where it needs to be stored.

A. Stacking strategy

In general the objectives of stacking strategies are [3]:

- Efficient and timely transportation from quay to stack and further destination and vice versa.
- Avoidance of unproductive moves.
- Efficient use of storage space.

In contrast to conventional stacks where the yard crane is responsible for all the moves including rehandles, rehandles do not directly influence the performance of the stack in the VCT. A four floor high VCT stack already contains eight ScLs, which have enough idle time to perform the rehandle moves. Therefore the objective of the stacking strategy for the VCT is to maximize the number of container moves per hour, without compromising on storage capacity. To achieve this, first a basic structure for the stacking strategy is defined after which the optimal location of the container is determined based on weighting factors. Two types of containers are distinguished in the stacking strategy; import and export containers. Import containers arrive per vessel and leave the terminal per truck. The exact time of a container pickup at the truck gate is not known beforehand. These containers are always stacked in the free access slots, so no containers ever have to be moved out of the way before the import container can be reached. The export containers arrive either by vessel or truck and leave per vessel. Based on stacking strategies in conventional terminals the export containers are grouped together in the stacks based on weight of the container, service and port of discharge [4]. The containers are placed in a bay in such a way that the heavier containers (going in the vessel first) are the first containers to reach by the ScLs. Containers of the same group arrive randomly over the days before the vessel arrives. Therefore, as soon as a container is stored in a bay, the surrounding slots are reserved for other containers of the same group. Because the containers stored in the exact middle row in a bay can only be retrieved when there is no container at the lowest position in the two adjacent bays, a reservation for a group of containers consists always of six or nine slots.

Following the basic structure, the exact location for a container is determined when it is unloaded at the QC or
delivered at the truck gate. Spreading the workload over the different stacks when loading a vessel is important in RMG yards since only one crane per stack serves the interchange of containers with the horizontal equipment at the waterside [5]. For the VCT this is even more important since the flow of import containers moving stack-out is also handled by the same crane (stack-out RMT). When an import container arrives, the following steps are taken:

- **Step 1**: Get a list of all empty free-access slots, and store this list together with the information on the location of every slot in terms of floor and stack. The slots that are already reserved for containers under way are left out.
- **Step 2**: Determine the occupancy of the RMTs for every slot in the list by considering the number of containers going to each RMT. The number of containers is multiplied by a weighting factor so that the slots located in stacks with a large number of orders get the highest penalty.
- **Step 3**: Determine the occupancy of the free-access slots per floor of each slot in the list and multiply this with a weighting factor. Slots in floor with a lower occupancy receive a lower penalty. The penalty is added to the result of step 2.
- **Step 4**: Sort the slots based on the penalty. The slot with the lowest penalty is the best slot for this container.

When an export container arrives, it is first determined if there is already a suitable location for the container in an already existing reservation for containers of the same group. A suitable location means that there is a slot reserved for the same group and also specifically for the weight class of the container. If multiple suitable locations are found, then the following steps are taken:

- **Step 1**: Determine for every slot the occupancy of RMT, and add this to the penalty of that slot.
- **Step 2**: For every location multiply the floor it is located with a weighting factor and the expected dwell time of the container. If the expected dwell time is relatively long, a higher location in the stack might be preferable to minimize the number of moves to the higher floor. Add the result of this step to the result of step 1.
- **Step 3**: Select the slot with the lowest penalty.

If no suitable locations exist, a new reservation has to be made. The location of the new reservation is again determined by rating the different options for a new reservation based on different parameters. For determining the optimal location for a new reservation, the following steps are taken:

- **Step 1**: Determine what the size of the reservation should be. When a container is delivered per truck a reservation of six slots is made. When the container is delivered per vessel the size of the reservation can be determined on beforehand, based on the number of containers of the same group unloaded by the vessel.
- **Step 2**: Determine the maximum number of reservations of the same group per stack, based on the expected number of containers for the group.
- **Step 3**: Make a list of the possible locations for new reservations of the size specified in step 1 is made.
- **Step 4**: Determine for every slot the occupancy of RMT, and add this to the penalty of that slot. Slots located in stacks with a large number of orders get the highest penalty.
- **Step 5**: For every location determine the number of slots reserved and occupied by containers for the same group and subtract the number of slots of the same group allowed per stack. This step makes sure that containers of the same group are divided over the different stacks. Multiply the difference with a weighting factor and add this value to the result of step 4.
- **Step 6**: For every location multiply the floor it is located with a weighting factor and the expected dwell time of the container. If the expected dwell time is relatively long, a higher location in the stack might be preferable to minimize the number of moves to the higher floor. Add the result of this step to the result of step 5.
- **Step 7**: Sort the locations based on the penalties. The location with the lowest penalty is the best locations for the new group.

### B. Dispatching

Dispatching is determining for the equipment what orders they need to perform. For the RMTs the container to be handled is already determined by the sequence in which the containers arrive over the mezzanine floor or are dropped at the transfer point on the ground. The elevator can select orders from the storage floor or the mezzanine floor. The dispatching of the elevator is selecting either a stack-in or stack-out order based on the number of containers on the mezzanine floor. Balancing the stack-in and stack-out containers on the mezzanine floor generate a constant flow of containers to the stack-out RMT without flooding the mezzanine floor. The ScLs determine the sequence in which the containers are delivered to the QCs and the truck gate. The ScLs dispatching aims at keeping a constant floor of containers to the stack-out RMT. At any moment in time all containers that need to be loaded into a vessel are known. However, when the ScL keeps moving containers for the vessel, the incidental orders to the truck gate are delayed due to the number of export containers already waiting to move to the vessels. The ScLs are therefore allowed to work only 20 orders ahead.

### IV. Typical ASC Terminal Characteristics

An ASC yard is a high density fully automated storage yard. A typical ASC yard consists of multiple stacks perpendicular to the quay. Each stack is served by one, two or in some cases even three automated rail mounted gantry cranes. These cranes can either be passing or non-passing [6]. The typical stacking height of a yard crane is five containers high and the span of the crane can be 8 to 12 containers wide [7].
### Table I. Specifications of a typical ASC crane.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gantry speed</td>
<td>4.5 m/s</td>
</tr>
<tr>
<td>Gantry acceleration/deceleration</td>
<td>0.3 m/s²</td>
</tr>
<tr>
<td>Trolley speed</td>
<td>1.0 m/s</td>
</tr>
<tr>
<td>Trolley acceleration/deceleration</td>
<td>0.3 m/s²</td>
</tr>
<tr>
<td>Spreader hoisting/lowering speed</td>
<td>0.5 - 1.0 m/s</td>
</tr>
<tr>
<td>Spreader acceleration/deceleration</td>
<td>0.35 m/s²</td>
</tr>
</tbody>
</table>

The layout of an ASC yard depends on the requirements of the terminal. In general two factors play an important role when designing a layout:

- The required storage capacity of the yard.
- The required handling capacity of the yard to the water side and the land side.

As a rule of thumb a single stack in an ASC yard is able to perform 16 moves per hour to the water side and 10 moves per hour to the land side, assuming that each stack is equipped with two non-passing ASC cranes. The specifications of a typical yard crane are presented in Table I. These specifications are used when simulating the ASC yard.

### V. Experiments

The experiments are conducted in two separate models of container terminals; One for the ASC yard and one for the VCT. The basic structure for each of the models is the same. The only differences between the two models is the type of storage yard, and the stacking and dispatching strategy.

#### A. Simulation Model

To compare the performance of the VCT and the ASC a discrete event simulation model is developed in eM-plant [8] by the use of the TIMESQUARE library [9]. The performed experiments test the performance of the storage yards under peak conditions, which means that there is always a vessel for each of the QCs and that a constant flow of trucks arrive at the truck gate. The orders are generated randomly. The vessel selects containers from the yard that are destined for the service of the vessel. Other unload orders and load orders from the truck gate are randomly generated. The transport over both terminals is handled by shuttle carriers. The routing and collision avoidance is not taken into account, so each vehicle drives the shortest route without taking into account other vehicles. The number of vehicles is set high enough to ensure the performance of the yards is not influenced by the performance of the shuttle carriers. Each experiment runs for eight hours. The first hour is assumed the warm-up hour and deleted from the results. The simulation randomly generates the containers to fill the yard before the start of the simulation. Each container is generated with random values based on the described scenario. After the containers are generated they are allocated based on the stacking strategy described later in this section. This concludes the initial build of the yard.

The TIMESQUARE library contains the basic objects for a container terminal (e.g. QCs, terminal operating system (TOS), containers, etc.) and is used as a basis for the simulation models. For the ASC model no extra objects needed to be added to the library. For the VCT the following objects are added to the library: Mezzanine floors, RMTs, ScLs and Elevators. The TOS handles the dispatching of all terminal equipment, order handling and storage strategies for the containers. For the ASC yard, conventional stacking and dispatching rules are used in the simulation. Containers are allocated based on their weight, location, group, destination, etc. For the VCT, the in Section III developed strategies are used. The ASC model has already proven to be a valid model based on the numerous projects it has already been used in. The validity of the VCT is tested by reviewing 3D data resulting from the simulation with the designers of the VCT and comparing the results with their expectations.

The following simplifications are made in the simulation models:

- In the VCT the temporary storage on the mezzanine floor is not moving over the mezzanine floor between the elevator and the RMTs.
- The simulation models only handle 40ft containers, because the process of handling two 20ft containers on one super skid has not yet been designed for the VCT. It is possible to replace all 40ft containers by a single 20ft container, but this will impact the storage capacity of the yard.
- The model of the VCT does not take into account the delivery of the super skids. The super skids are assumed to be available when a container is lifted into the stack by the RMT. When the container is discharged from the stack, the super skid is removed again.

#### B. Scenario

The two models have exactly the same scenario as input for the simulation. The developed scenario is a balance between what can be assumed as an average terminal and where the VCT could be applied. The influences of changes to scenario are discussed in the conclusions. The basis for the simulation is an 1.4 million TEU per annual terminal with six QCs. The performance of the QCs is set high compared to reality to evaluate what performance the yards can reach. Each QC is capable of performing 50 moves per hour. At the truck gate 125 trucks per hour arrive either picking-up or delivering a container. The transshipment ratio is 55 percent, and 15 percent of the arriving containers is empty. These settings result in an ideal distribution of types of container in the VCT yard, so no exceptions need to be made when allocating a container. For example storing an import container in one of the slots in the middle of a stack. A summary of the scenario is presented
in Table II. Based on the scenario, layouts for the VCT yard and the ASC yard are developed. The results of both layouts are presented in Figure 3. The ASC yard consists of stacks of nine container wide and five containers high. The length of each stack is 34 TEU.

### C. Results

Table III shows the results of the experiment on the performance of the VCT. Table IV shows what percentage of the stacks capacity is used to give an insight into what performance might be possible in the future. Table V shows the result of the experiment for the ASC yard.

The results from the experiments on the VCT show that the VCT is capable of reaching the performance defined in the scenario. The idle times of the equipment in the VCT show that the ScLs have a high percentage of idle time. This can be explained by the fact that there are eight ScLs in a stack with four storage floors, while the stack is equipped with only elevator and two RMTs. The difference between the idle time of the stack-in RMT and the stack-out RMT can be explained by the selection of orders for the QCs. Containers arriving at the terminal allocated to a location in the stack based on the stacking strategy and thus sent to stacks with the lowest occupancy for the stack-in RMT. The orders that are performed by the stack-out RMT are orders loading orders for trucks or vessels. The loading orders for the QCs are selected per QC. In the model the sequence of the stack-out orders is only optimized for workload distribution per crane. Often multiple QCs are loading vessels and require containers from the same stack, increasing the workload in one stack while in another stack the workload is fairly low. The elevator does also not have much spare productivity, but the dispatching of the elevator in the model only focuses on the number of containers on the mezzanine floor. If the dispatching of the elevator forces the elevator to perform more dual-cycle moves if possible, then the performance of the elevator can increase.

The results from the experiments with the ASC yard are presented in Table V.

In Figure 4 the handling capacity of the VCT and the ASC yard is compared. The ASC yard performs slightly better for the number of LS and WS moves. Figure 5 shows the area required for both storage yards. As can be seen from the figure, the storage yard of the VCT is 38 percent smaller than the ASC yard. The calculation for the total area of the yard also takes into account the lanes around the stack and the area between the yard and the truck gate.

### VI. Conclusions & Future research

In this research the performance of the VCT has been evaluated. The results show that the number of ScLs per stack can be lowered without losing performance of the stack. The bottlenecks in the storage processes are the RMTs. The performance of the stack-in RMT is expected to increase if the spread of workload is taken into account when planning the containers that need to be loaded into vessels by the QCs.

This research has shown that the VCT can be compared with an ASC storage yard in terms of storage and handling...
capacity. The required space for the storage yard is significantly smaller for the VCT yard.

It is important to notice that the performance has only been tested in a single scenario. Changes to the scenario might influence the performance of the storage yards. A different ratio between import and transshipment containers creates more rehandles in the VCT when import containers also need to be stored in the middle of a storage floor. However in the design of the VCT, with two ScLs per storage floor, these extra rehandles do not directly influence the performance of the stack. The fact that only 40ft containers are used in this comparison means that the VCT loses no capacity. When also 20ft containers need to be handled, a system must be developed in the VCT to combine and split containers on one super skid. It is also possible to place a single 20ft container on one super skid, but this influences the storage capacity of the yard. In the ASC yard two 20ft containers can be placed together in a 40ft slot, so the storage capacity of the ASC yard is not influenced. The following recommendations are done for further research:

- **The VCT has only been tested in a single scenario.** The simulation model could be used for future research when an actual possible site for the VCT is determined. It is recommended that the VCT is tested in an environment where it can be used. An actual site for a terminal might give a different layout and container flow, influencing the decision for one storage yard or the other.

### References