A SIMULATION STUDY OF NEW GENERATION CONTAINER TERMINALS SUITABLE FOR 8000 TEU VESSELS

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Abstract

The container traffic world-wide is still increasing, while at the same time ship sizes grow to jumbo container vessels with capacities of 8000 TEU.
This increase in scale combined, with the required high service levels of the terminal, results in high logistic demands.
When overlooking the mentioned developments a logical step would be the design of container terminals, using the warehouse stacking concept, with a high automation degree of the different terminal components..
To evaluate the possibilities, the Delft University of Technology in co-operation with the National University of Singapore, carried out an orientating study to estimate the capacity and to assess the performance of such a terminal.

INTRODUCTION

The objective of the study is the development of the functional design of a highly automated container terminal using the **warehouse-stacking** concept. Initially this study considers only sea to sea transport, so a transhipment terminal called by jumbo container vessels and feeder vessels, neglecting the hinterland transport.
The following starting points were used:

1. Capable of handling jumbo container vessels of about 8000 TEU
2. Minimising land usage by applying warehouse stacking
3. Using as much as possible existing technology.

Regarding ship waiting times, multiple container berths terminals may allow higher occupancies than terminals with one or two berths. This study considers a three-berth unit of a multiple berth terminal. The three-berth unit consists of a jumbo container berth in the middle and adjacent two feeder berths (see Figure 1). After the choice of the different terminal components the operational processes of the terminal unit were modelled and analysed by using a traffic flow simulation model. The simulation study was highly concentrated on the transhipment, internal transport and stacking processes of the terminal unit.

CHOICE OF THE TERMINAL COMPONENTS AND CAPACITIES

Portainers

The development of portainers in the last couple of years has shown a considerable increase in production. In this study no particular concept was chosen, only an assumption on portainer productivity was made. Within the framework of FAMAS (First All Modes All Services) studies [4] a logistic analysis showed that average cycle times, based on hatch cover vessels, of 58 seconds are possible. This leads to a production of about 62 moves per hour.

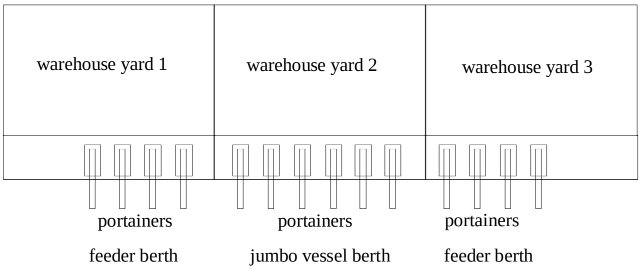


Figure 1 Configuration

Container storage system

One of the starting points in this study was to minimise the land usage. In this respect stacking height is an important factor. Normally containers are stacked on top of each other. This conventional stacking method is restricted by ISO standards. Moreover when containers are stacked on top of each other, shuffling and reshuffling of containers is a time consuming process. Placing containers in racks stacking height is not restricted to ISO limits and more important it allows for a random container access, greatly decreasing the retrieval and depositing time.
Currently several alternatives of container warehousing are investigated. The warehouse concept, applied in this study, is presented in Fig. 2 and 3. The containers are stored from the second floor of the warehouse. The first floor is used for horizontal transport units (2 and 14) and the so-called service points (15) allow for a horizontal movement from the horizontal transport unit (2) to the elevating transfer vehicle (5).
A service point consists of one container location upon an elevated area with the same height as the horizontal transport unit. Each warehouse unit is provided with 1 warehouse crane resulting in 5*14= 70 cranes.

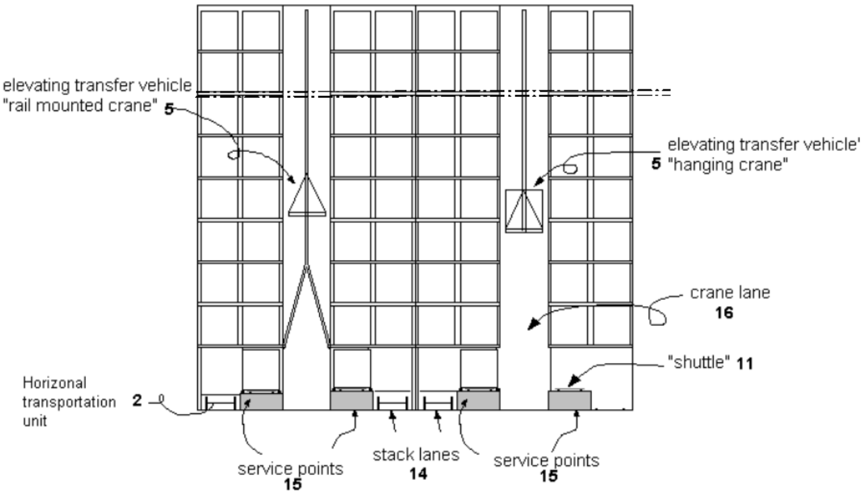


Figure 2 Cross section warehouse

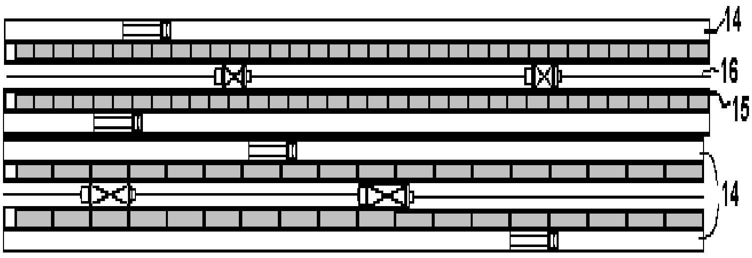


Figure 3 Top view warehouse

Horizontal transportation

The choice of the horizontal transportation equipment was mainly based on land usage. The rail guiding vehicles (RGV's) show the best performance in taking a turn. The layout of the rails consists of tracks oriented parallel and perpendicular to the quay.

LAYOUT OF THE TERMINAL

Warehouses

In the chosen layout 5 warehous rows are situated behind the portainers parallel to the quay Preliminary calculations showed that the total capacity of the warehouses of about 24000 TEU is required. Based on this figure the capacity behind berth 1 and berth 3 both was set at 6860 and behind berth 2 for the jumbo vessels at 10290. By taking 5 warehouse rows the stacking height had to be 12 stories of warehouse racks (see Figure 2 and 3).

Transport lanes

Principally three types of transport lanes are distinguishes:

1. Warehouse lanes inside the warehouses
2. The portainer service lanes used for the supply of containers to the portainers.
3. The inter-berth lanes, orientated parallel to the quays, provide the connections between the warehouses of the different berths.
4. Yard lanes, orientated perpendicular to the quays, connect the warehouse-lanes with the inter-berths lanes and the portainer service lanes.

Initially 10 warehouse lanes, 8 inter berths lanes, 2 portainer service lanes and 15 yard lanes were applied. During the unloading procedure each portainer is served by a RGV loop. In this way a tight grid can be formed.

CONTAINER HANDLING STRATEGIES

An important aspect of terminal design is determining the most efficient way of transporting the container over the terminal. Especially when the stacks can be placed directly behind the berths as is the case in this study.
After a sensitivity experiment the fast unloading/adjacent loading strategy was applied.

Fast unloading/ adjacent loading strategy
If the containers from the vessel are stacked directly behind the unloading berth, the travelling distances for the horizontal transport will be limited. However if for example a feeder vessel, moored at berth 1, unloads all the containers in the warehouses directly behind berth 1, the loading procedure to the jumbo vessel implies horizontal transport from yard 1 toYard 2. The last mentioned procedure is called adjacent loading. Figure 4 schematically shows the fast unloading and adjacent loading procedure.

CONTAINER HANDLING PROCEDURES

Fast unloading

The fast unloading procedure is the same for all berths.
The RGV's delivering containers from the portainer to the warehouse stacks are driving in a circular motion. The direction of the circular motion depends on the location of the portainer. A consequence of this fixed direction of motion is that the RGV's can only reach 5 of the 10 warehouse stacking lanes of a stack-cluster.
The RGV's will not use inter berths lanes during the fast unloading process.

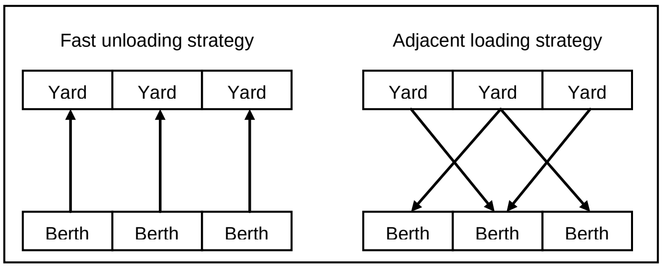


Figure 4: Fast unloading adjacent loading

Adjacent loading of a jumbo vessel

The adjacent loading process of a jumbo vessel at berth 2 takes containers from berth 1 and berth 3. The RGV's will use the inter berth lanes. In order to spread the RGV flows, half of the RGV's take outside inter berths lanes on the landside and the other half the outside inter berths lanes on the seaside. Two example routes are presented in Figure 5.

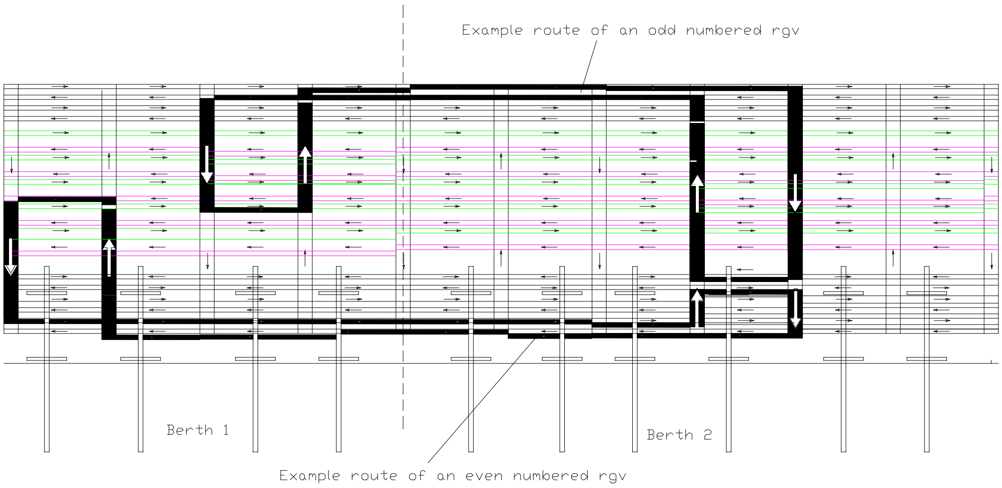


Figure 5 Adjacent loading of a jumbo vessel

COMPUTER SIMULATION

The container terminal concept has been simulated in Prosim software. Prosim uses the process description which is familiar with the object-oriented language. In the process description method the processes of all live components are described. Live means that these components are executing activities. Non live components or data components do not have a process description and are considered as data carriers. Prosim models consist of two sections:

1. A definition section

In the definition section all components with attributes, sets etc, are defined

2. The dynamic section

In this section dynamic behaviour of all components with the interactions with other components are described in the belonging modules.

SIMULATION RUNS AND RESULTS

Runs and boundary conditions

After having verified the model the simulation experiments have been carried out. Different states of the terminal unit were simulated to estimate the capacity and to identify the performance under different conditions. During these runs the boundary conditions specified in the next tables were

Vessel	Cap.	Through put [TEU]	Throughput [moves]
Feeder	1575	3150	2100
Jumbo	8000	9450	6300

Table 1 Boundary conditions vessels

Portainer	berth 1	berth 2	berth 3
Number	4	6	4
capacity [moves/h]	39-77	39 - 77	39 - 77

Table 2 Boundary conditions portainers

applied. Table 1 gives the data about the vessels, Table 2 about the portainers, Table 3 about the RGV's and Table 4 about the RGV's per portainer.

standard speed on berth-lanes [m/s]	3
standard speed on warehouse-lanes [m/s]	1
acceleration [m2/s]	1
turning wheels over 90^0 [s]	4

Table 3 RGV attributes

Activity	number RGV's
adjacent loading	10
fast loading	6
fast unloading	6

Tabel 4 RGV's per portainer

Simulation results

The highest occupancies of the terminal unit components are most revealing. Therefore only the results, with all berths occupied and with adjacent loading, are discussed in detail.

Adjacent loading of all vessels

Figure 6 shows the average occupancy per portainer, Figure 7 GRV waiting rows to be served by portainers and Figure 8 gives an indication of the waiting row in node 350.

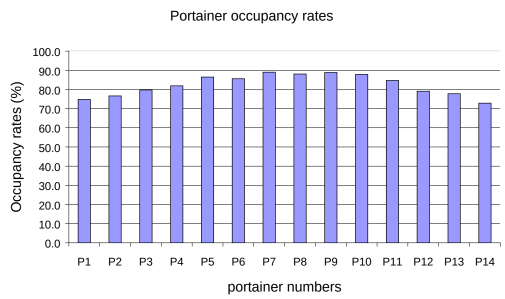


Figure 6 Portainer occupancy rates

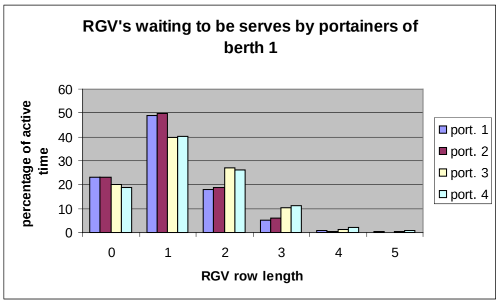
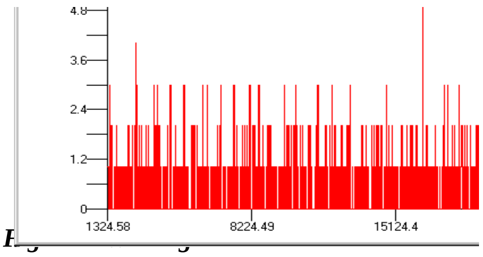


Figure 7 RGV's waiting to be served by a portainer



Node 350 (Fig. 13) is for instance the intersection between a warehouse lane and a yard lane behind berth 2 of the jumbo vessels. In general it was concluded that enough space is available to accommodate the waiting RGV's at the intersection points. Another important factor concerns the length of the waiting rows of RGV's to be served by cranes (see Figure 14). Again this length did not exceed the limits.

Waiting rows

Portainer occupancies

The differences in the occupancies of the portainers are explained by realising that the cycle distances of RGV's working for cranes at berth 2 are somewhat shorter than the cycle distances of RGV's assigned to berth 1 and berth 3.

Warehouse cranes occupancies

Also the warehouse crane occupancies were registered. Two different warehouse types are distinguished: for 20 ' and for 40' containers.
For the warehouses behind the Jumbo vessel berth occupancies of 34.7% and 23.2% were registered for respectively the 20' warehouses and 40' warehouses.
The figures for the Feeder berths are 43.3% and 29 % for respectively the 20' and 40' warehouses.
Table 5 gives the berth production during adjacent loading.

The unloading-loading concept

From results of the different run carried out, no major improvement was registered going from adjacent loading to direct loading. This means that removing containers from the unloading berth to

the berth where the containers have to be loaded is not necessary. So the strategy fast unloading adjacent loading is advised. Production rates with disturbances and random fluctuations.
Until so far no major disturbances in the terminal operation were applied.
In this stage of investigation it is not quite clear what kind of disturbances might happen moreover the variance of the actual portainer production rates are uncertain. This applies also for the production rates of the warehouse cranes. If random fluctuation of crane production rates and if disturbances up to about 15 minutes are inserted the handling rates presented in Table 6 are obtained.
If mooring times and unmooring times are added to values of the handling rates times in Table 6, the service time is estimated at 22 hours for a jumbo and 12 hours for a feeder vessel.

	number of containers	**service time [h]**
berth 1	1050	5.4
berth 2	3150	9.7
berth 3	1050	5.4

Table 5 Service times adjacent loading

	Handling rates [mvs/h]			**service times [h]**		
	f. unl.	adj. l	mean	f. unl.	adj. l.	mean
feeder	231	190	211	4.5	5.5	10.0
jumbo	334	300	327	9.4	10.5	19.9

Table 6 Handling rates and service times

TERMINAL UNIT CAPACITY

For a first estimation of the terminal unit capacity the queuing theory was applied. The capacity of the jumbo berth is decisive for the terminal unit capacity. An $E_3/E_3/1$ queueing system was applied (Erlang 3 for arrivals, Erlang 3 for the service times). With a demand of an acceptable waiting time of 10% of the service time, this resulted in a mean berth occupancy of 40%.
Based on this occupancy a yearly throughput of **2,886,000 TEU** can be achieved.
The land usage (without service buildings and RGV parking places) is about 170,000 TEU/ha.

CONCLUSIONS AND RECOMMENDATIONS

1. The optimal handling strategy for this terminal unit is fast unloading to the yard behind the berth of the vessel and loading from an adjacent berth.
2. The average production rates are 211 mvs/h for the feeder berths (4 portainers) and 327 mvs/h for the jumbo vessel berth (6 portainers).
3. Six RGV's per portainer are sufficient.
4. The occupancy of the warehouse cranes is rather low about 30% during adjacent loading of all berths; the number of cranes could be reduced
5. In the estimation of handling rates only minor disturbances have been included. A thorough study of disturbances on the production rates is necessary.
6. The annual berth production was calculated by using the queuing theory. For a better estimation simulation runs of one year should be carried out on a higher aggregation level.
7. A cost optimisation of the stacking height versus the number of warehouses should be carried out.

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