OPTIMIZATION AND SIMULATION OF OPERATING STRATEGIES FOR CONTAINER TERMINALS

Jan Kaffka, Chair of Transportation Systems and Logistics, TU Dortmund

Uwe Clausen, Chair of Transportation Systems and Logistics, TU Dortmund

Annette Chmielewski, Chair of Transportation Systems and Logistics, TU Dortmund

Torsten Schütte, Container Terminal Dortmund GmbH, Dortmund

ABSTRACT

TU Dortmund University developed a simulation suite for the Container Terminal Dortmund GmbH seated in the largest inland port in Europe located in Dortmund. This suite focuses on modelling processes, resources and strategies for container terminals and enables to optimize a terminal with simulation. The aim is to optimize the terminal by determining the best mix of operating strategies for crane control, stacking area, handling area and resource management. To achieve this, the current situation of the terminal and different future scenarios for operating the terminal were modelled with the simulation suite.

Keywords: Logistics, intermodal freight transport, simulation, optimization, container terminal, crane control, operating strategy, inland port

INTRODUCTION

Container terminals can be described as a complex material flow system with many subsystems, for example loading points, container stacks or handling equipments.
These subsystems interact with each other, hence there is a lot of stochastic influence and interdependencies within the decisions. This makes an optimization of a whole container terminal very complex and without technical and methodical support hard to handle. Optimization in one subsystem influences all other subsystems and therefore does not result in optimality for the whole system. Stahlbock (2007) and Steenken (2004) provide state-of-the-art summaries regarding operations and methods for optimization in these single subsystems.
Regarding to Voss (2007) the typical structure of a container terminal consists of two external interfaces: first, the quayside loading points, where containers are loaded on/off ships; second the landside loading points, where containers are loaded on/off trucks and trains.

Inside the terminal, containers are stored in container stacks with different zones for varying types of containers. Basically stacking zones can be distinguished into import and export zones. This classification is extended by zones for full and empty containers, containers with dangerous goods and for cooling containers. Additionally inland port container terminals contain zones for trailer and swap bodies.
A container stack is grouped into ground slots on which containers are stacked in a pile with a certain maximum height. The authors assume that the dimension of a ground slot is equal to a 20 feet container. This means that 40 feet containers are stored on two ground slots. Furthermore it is assumed in the simulation model that a container can only be stacked onto a container with the same size. The maximum height of the container pile is restricted either by the controlling strategy or by the handling equipment.
After the arrival of a vehicle in the terminal containers are unloaded and stacked in the terminal. Than the export containers are loaded on the vehicle. After that the vehicle is ready to depart. In deep sea container terminals, unloading/loading of vessels and trains is done by quay cranes, transportation of containers between loading points and stacks by straddle carrier or reach stacker and stacking by cranes or straddle carrier. In inland port container terminals the main handling equipment are rail mounted gantry cranes on one rail. These cranes straddle all operation areas of the terminal and execute all handlings (see figure 1). Reach stacker or straddle carrier are assembled only to assist in times of high system loads. Because of that, the scope of this paper is limited to a container terminal without reach stacker or straddle carrier.

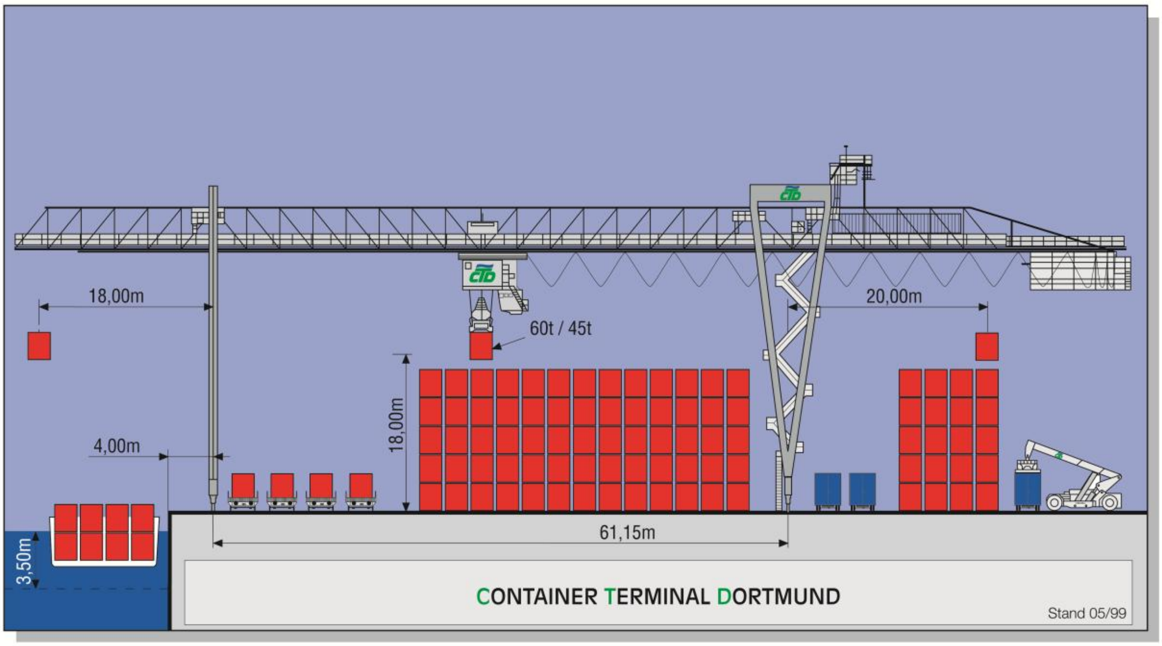

Figure 1 – Container handling in inland port container terminals

To optimize the overall system with all its stochastic influence and interactions, the method of discrete event simulation is used, which provides the opportunity to create an experimental model and decide the best recommended course of action (Canonaco (2007)).
For simulating container terminals in this paper a self developed simulation suite based on the simulation software Enterprise Dynamics 7.2 is used. This software contains some

preconfigured basic and logistics atoms (e.g. queues, server, conveyors) which can be used, but the terminal specific atoms had to be developed for the task of simulating container terminals. A simulation model representing layout and material flow of a container terminal is built based on these atoms. This is done as accurate as needed and less detailed as possible (Wenzel (2008)). The scope of work in this paper has been restricted to inland port container terminals, but the simulation suite can also be used in deep see container terminals.

CONTROLLING STRATEGIES

According to Lee (2008) the main issue of a deep see container terminal is to serve the large container ships within the contract time. Inland port container terminal serve as a hinterland hub for deep sea container terminals and so it is very important that these terminals maintain the time tables for trains and barges to ensure the just–in-time delivery of the containers to deep see terminals. Another factor is the waiting times of trucks. The hinterland hub disposes and collects the shipments in the regional area. The trucks have to maintain delivery time windows at the shippers or consignees in the region, therefore short waiting times for trucks inside the terminal are important and expected from forwarders.
To reach these goals the controlling strategies are key success factors for terminal operators. This paper tests controlling strategies for inland port container terminals. Those can be classified into three categories:

1. Means of transportation-loading point allocation
2. Crane control strategies
3. Operational strategies

All these strategies influences each other, e.g. different terminal layouts change the routing of the cranes, so that it is necessary to adjust them all together for a specific terminal.

Means of transportation-loading point allocation

The allocation of means of transportation to a loading point is implemented in a central strategic atom (terminal control) of the simulation suite. The terminal control primary routes the vehicles through the system and makes decisions, e.g. which area of handling is allocated to the vehicle. An intelligent allocation of vehicles to handling areas is a critical success factor for a terminal. For example, if a truck is allocated to a loading area within an effective range of a different crane than the source area of the container, one crane has to be moved out of his effective range and cannot work short-term due to waiting reasons.
Basically the cranes work in effective ranges (all areas can be handled by the crane) which are mostly independent from each other. It is possible for each crane to work in the range of another crane, but this should only happen to avoid dead-lock situations. The modelling of working ranges permits to assign every stack, truck loading point, train loading point and ship loading point to one specific crane.

The first aim of the terminal control is to ensure that the pick-up-point and the drop-off–point of a container are within the effective range of only one crane. Thereafter the terminal control determines the loading point where a vehicle is loaded or unloaded by using the shortest path under the restriction of the effective range of the crane. This happens primarily for trucks because the loading points for trains and ships are given by the stowage plan.
Generally there are two cases of truck handling: a truck retrieves a container (it can also deliver one, but important is the retrieving) or a truck only delivers a container. In case of retrieving a container, the terminal control always tries to allocate a free truck loading point based on the shortest path of the crane from the actual position of the container (e.g. in stack) to the loading point. In case of only delivering a container, the terminal control has two different settings to allocate a loading point to the truck. On the one side the control allocates the loading point by random using a random generator. The other setting always assigns the first free loading point, beginning at the first loading point in the effective range of a crane, to the truck (FiFo-principle).
Concerning ship and train-loading point allocation, the possibility for implementing strategies is restricted by the stowage plan: ships are unloaded and loaded according to the stowage plan and trains were unloaded and loaded according to the shortest path under the existing weight and size restrictions (e.g. loading pattern for a wagon).
The allocation of a container to a position in the stack is not done inside the terminal control, because there is a huge time gap between the loading-point allocation, when the vehicle enters the system, and the actual handling of the container. At this point the optimal position in the stack might be no longer the optimal position due to other container handlings inside the terminal. Hence, the stack position is determined online in the crane control.

Crane control

The crane atom in inland port container terminals is a multi crane module consisting of up to five rail mounted gantry cranes on one rail. Due to the fact that these cranes span the whole handling area of a terminal, the crane handlings are the main value added process and therefore the control of the cranes shows a huge optimizing potential for terminal operations. The crane control is realized in the simulation suite as a peripheral control unit which controls the crane handling online, which means that at every change of system status a new optimal solution is calculated. The main issues considered by the crane control are

1. Container ground slot allocation
2. Handling task sequencing

Container ground slots are allocated to a container by determine the shortest path from the loading point to a possible ground slot or from possible ground slot to target loading point, if the loading point is known at the time of handling. The ground slot allocation always works under the ground slot restriction, which implies that a container stack has a maximum stack height and only containers of the same size can be stacked to one ground slot. Furthermore the container must be stacked in the right stacking zone (e.g. export zone, full container zone) and must be within the effective range of the handling crane. An allocation to other stacking zones or cranes can only happen if the stacking zone or the stack within the effective range of the crane is full. This happens to avoid deadlock situations.

The handling task sequencing is the core of the crane control and decides which container is to be handled next by a crane. This decision is triggered every time the system status has changed (e.g. a crane picks up or drops off a container). This paper includes both the classical FiFo strategie and Next-Best strategies which handles the task with the shortest travel time to the pick up ground slot. This are good strategies for the purpose of controlling a crane which deliver a good task sequence but only look at company specific requirements like travel time optimization.

However, a container terminal is subjects to market requirements too. The main market requirements are the waiting times of the means of transport, especially of ships and trains, but also trucks. If a truck stays to long inside the terminal, the forwarder intends to use another container terminal for the next time.

The company and market requirements for specific terminals are often different so that a handling task sequencing was developed which can be adjusted to the specific needs of a terminal. This handling task sequencing strategy with a priority number was developed by Lampe (2006) for a solo crane bimodal terminal. The paper enhances this strategy to a multi crane module in a multi modal terminal like a container terminal.

The core of this strategy is the priority number. This number describes the degree a container inside the handling area qualifies for handling. The container with the highest priority number is the best container to handle next by a crane. The priority number consists of a priority parameter for every company and market requirement and their weighting and criterions of exclusion. The priority number is calculated by the following term:

$$P_j = \sum_{i=1}^{n} p_i \cdot g_i \qquad j \in \text{Container}; p_i \in [0,1]$$

In which P is the priority number, n is the number of priority parameters, p_i is the different priority parameter and g_i is their weighting.

The priority parameter for every requirement is $p_i \in [0,1]$ so that the best task for each requirement is the one closest to one. If the number can be higher than one, there is no possibility to compare the different parameters with each other, because one parameter can be dominant and always overrule the others. The importance of a parameter for the terminal operator can be adjusted by the weighting.

The number of priority parameters can be adjusted individually to the requirements of the specific terminal. In case of this paper the priority parameters used are:

1. shortest path,
2. shortest waiting time of the vehicles and
3. cut off time of vehicles.

In addition, the priority number has to consider criterions of exclusion, which make a handling of a specific container impossible, by assigning priority numbers lower than zero. Criterions of exclusion are for example if a collision with another crane can happen if the container is handled, or if the container is inside the pile of a ground slot and other containers has to be handled first to reach this container. If such a criterion of exclusion is calculated for a handling task, the priority number is set to lower than zero so that a crane will never handle this task.

Operational strategies

Operational strategies describe all other strategies affecting the daily operations in a terminal. This are:

1. Layout variations
2. Number of gates and
3. Maximum stack height and stack organisation.

As described above, the stacks are divided into different zones for different types of containers. These zones can be at different positions in the stack and can have different dimensions. For terminals it is important to determine an optimal layout concerning the alignment of the zones. In this paper different layouts were developed with the Container Terminal Dortmund GmbH and tested within the simulation experiments. In these layouts every effective range of a crane is divided into zones for every container type (e.g. empty, full, export, import) except the zones for dangerous goods and cooling containers. This is founded in the fact that these zones need special structural measures and cannot be relocated.

Another operational decision is the number of front gates that are opened for truck dispatching. Opening a fewer number of gates than needed leads to longer waiting queues in front of the gates. Otherwise a high number of open gates can lead to high and unnecessary personnel costs.

The last operational decision in this paper is the maximum stack height of container piles on a ground slot. The higher these piles are the higher is the number of restacks. Therefore, the strategy is always to minimize the maximum height of the stacking piles by determining that the maximum height should always be four rows, and the fifth row should only be used to catch a temporary high system load. In addition, there are also different possible stack organisations. It is possible to stack empty containers in piles only for one ocean carrier or random, because ocean carriers often order a high amount of empty containers from an inland port container terminal serving as a depot to a deep sea container terminal. With the strategy of piles for only one ocean carrier the terminal can reduce the restacking inside the container stack.

EXPERIMENTS AND RESULTS

To achieve the aim of optimizing container terminals by determining the best mix of operating strategies the current situation and different future scenarios are modelled with the simulation suite. The process of such a simulation study can be seen in figure 2.

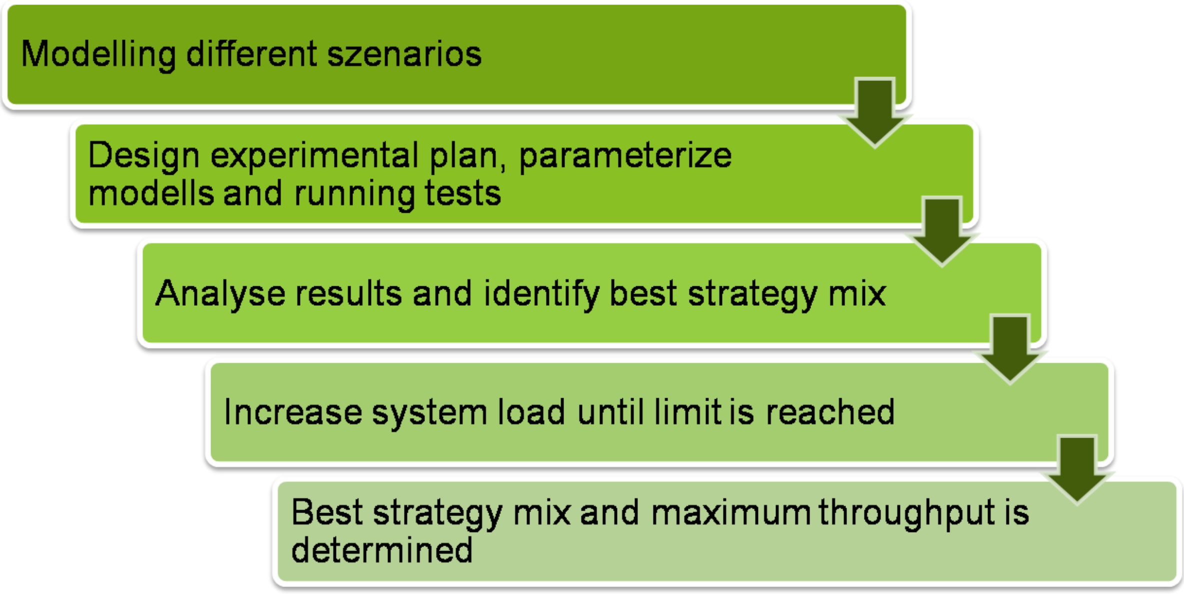

Figure 2 – Process of a simulation study

Based on the scenarios an experimental plan is predesigned, the models are parameterized regarding to the experimental plan and simulation tests take place for every different model. The results from these simulation tests are analysed and compared regarding to a developed performance measurement catalogue. An example of a possible performance measurement catalogue can be seen in figure 3.

Vehicles	Cranes	Gate
Cycle time	Efficiency/crane	Efficiency/gate
Waiting time	Cycle time/handling unit	Number of waiting vehicles
Time at loading point	Handling factor	Process time/vehicle
	Empty travel ratio	
	Full travel ratio	
	Idle ration	
	Direct handling ratio	

Figure 3 - Example for a performance measurement catalogue.

First, experiments are done for the current situation of the terminal. Thus the simulation can be validated on the one hand and a reference result for comparing the results of the different simulation runs is created on the other hand.
All experiments are based on the current system load of the terminal to determine the best operating strategy mix for the specific terminal with the current system load.
This mix of operating strategies in the case of this terminal consists of the Means of transportation-loading point allocation and crane control explained before. With the use of these strategies the terminal can reduce the overall cycle time of a truck by 3% and the time

of a truck at a loading point by 6 %. Therefore more trucks can be handled in the terminal which increases the capacity of the terminal. Another important figure is the handling factor. This figure describes the ration from paid handlings to overall handlings. The intention of a terminal is to lower this factor. A low factor indicates that less depot to depot handlings were done and the productivity of a crane was raised. Due to identifying the best strategy mix, the handling factor can be decreased by 2,5%. Also the Empty travel ratio of the cranes can be reduced and the full travel ratio of the cranes can be raised by 4%. In addition, the efficiency of all cranes in the terminal is more uniform. Due to the fact of more capacities at the loading points and more productivity of the cranes, the terminal operator has the opportunity to raise the maximum throughput of the terminal.

After finding out the best operating strategy mix the maximum throughput is determined with this strategy bundle. Therefore experiments were taken with slowly rising system loads until the terminal system reaches its limits. At this point the maximum throughput is reached.
With the simulation and the implemented controlling strategies, especially the handling sequencing with priority number, we were able to raise the efficiency of the cranes and reach a more uniform efficiency in a multi crane module compared with the current situation. Furthermore, we lowered the cycle time of the trucks, and met the schedules for ships and trains. In addition we lowered the direct handling factor. The lower this factor the more income the terminal has.
By defining the maximum throughput of the terminal we achieved a raise of the possible throughput by 30% based on the best operating mix and a raise of 27% of paid handlings.

CONCLUSIONS

This paper showed that optimization with simulation brings a benefit for terminal operator. Especially the handling sequencing with priority number showed to be more efficient than the standard strategies like next-best and enhanced the performance of the inland port container terminal.
Failures in the material flow can be identified with the simulation suite and new strategies can be tested in a virtual model, without cost-intensive real time tests. The suite can also be used as a daily control panel to plan the deployment and the operating strategy mix for the upcoming day. By the use of the developed simulation suite it is possible to optimize container terminals for every system load that can be handled by the terminal.

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