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REVEALING GAPS IN THE MATERIAL FLOW OF INLAND PORT CONTAINER TERMINALS ALONGSIDE THE DANUBE WITH SIMULATION

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ABSTRACT

Central European inland waterways are presently utilized way below their theoretical carrying capacity. For instance, cargo transported on the Danube is only 10-20% of that transported on the Rhine. To support an increase of transport flows on inland waterways (especially container transport on the Danube) and to contribute to a significant modal shift from road to waterways, operators have to be enabled to improve their economic position by improving the material flow in the handling points of the intermodal transport chain, container terminals, which oftentimes form a considerable bottleneck due to e.g. long processing times. In this paper, gaps in the material flow of container terminals alongside the Danube are revealed with the use of simulation. The Simulation enables the terminal operator to create an experimental model and decide on the best recommended course of action.

1 INTRODUCTION

Ship owners expect an absolute maximum of loading capacity with respect to the vessel's dimensions with a minimum of necessary propulsion power. It is a clear goal of any shallow water ship development to satisfy the needs of growing container transport by enabling inland vessels to carry a maximum of containers using a minimum of resources - not only for an efficient container transport on the Rhine and its waterway system, but on the Danube and 80% of the European Inland Waterway System. Thus, the FP 7 funded project "NEWS" works on developing and validating a novel container inland vessel accompanied by an appropriate, special-designed and integrated logistics system.

The container transport market is mainly determined by the development of the GDP in the different states and trade regions, demographic changes and changes in per capita income. Till 2020, an average annual growth of 6% in the global container seaborne trade is forecasted (ISL 2011). This short- to medium-term development will extensively influence seaport hinterland logistics systems regarding all transport modes, giving special attention to inland waterway transport (IWT). Just for the Port of Constanta (Romania), in 2006 approx. 16.000 TEU have been transported on inland waterways, in that case the Danube-Black Sea Canal (Via Donau 2007), which would have led to approx. 102 transports/year by using NEWS (assuming a capacity of 156 TEU for the self-propelled vessel).

One aim of the "EU Strategy for the Danube Region" is to increase cargo transport on the river by 20% by 2020 compared to the year 2010 (EU Regional Policy 2011). This growth will only be manageable if the entire transport and logistics chain, including port infrastructure and logistical processes, is optimized simultaneously. Therefore, not only technical aspects are tackled, but also the port infrastructure is analysed.

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This paper shows results of the port infrastructure analysis with regards to NEWS. The goal of this paper is to identify gaps in the material flow of inland port container terminals in an very early stage of new planning or expansion planning of container terminals. To achieve this goal, we develop a low Level-of-Detail simulation suite for capacity planning of container terminals in an early stage. The simulation provides the opportunity to improve the operations in an overall system with all its stochastic influence. It enables the operator to create an experimental model and decide on the best recommended course of action. Furthermore, the operator can model future scenarios with new terminal layouts and logistic concepts. In a first analysis gaps in the material flow of a successful exemplary port located at the Danube are revealed with the use of simulation.

2 LOGISTICAL NETWORK STRUCTURE AT THE DANUBE

To absorb and to promote the aspired growth in container transport created by NEWS and its increasing transport capacity, inland port container terminals have to transform from single transhipment points to comprehensive logistics partners. Container terminals can be differed into deep sea container terminals and inland port container terminals. A deep sea container terminal serves the large container ships within the contract time. According to (Lee et al. 2008) this is the main issue of deep sea container terminal handling. Large container ships have to be handled as fast as possible so that the lay days remain as short as possible. Unloading/loading of ships and trains is done by cranes, transportation of containers between loading points and stacks by straddle carrier or reach stacker and stacking by crane or straddle carrier. All these subsystems work separated from each other with interfaces between them; hence, there is a lot of stochastic influence and interdependency within the terminal operations. This makes an improvement of a whole container terminal very complex and without technical and methodical support difficult to handle. An improvement in one subsystem influences all other subsystems and therefore does not necessarily result in an improvement for the whole system. On the contrary, inland port container terminals serve as a hinterland hub for deep sea container terminals. Containers from the collecting area are stored in the terminal and delivered just-in-time to the sea port. Furthermore, incoming containers are dispatched in the hinterland to the consignee of the shipment. To ensure the delivery of containers to deep sea terminals in time it is very important that these terminals meet the time tables for trains and barges.

Within the Danube Region, inland port container terminals differ strongly concerning their size, equipment and offered range of service resulting from factors such as TEU volume handled, expendabilities and financing possibilities. To improve the logistics system and to develop new infrastructural concepts for any type of inland port container terminals, it is necessary to evaluate all possible types of container terminals and cluster these terminals. As a result, a total of 151 facilities/terminals have been identified doing handling activities alongside the Danube. Due to the fact that NEWS is focused on container transport, the initial list was cut down to the 24 container terminals located at the Danube. This list of 24 container terminals serves as a basis for setting different container terminal clusters. For each cluster an exemplary terminal is chosen and bottlenecks are revealed.

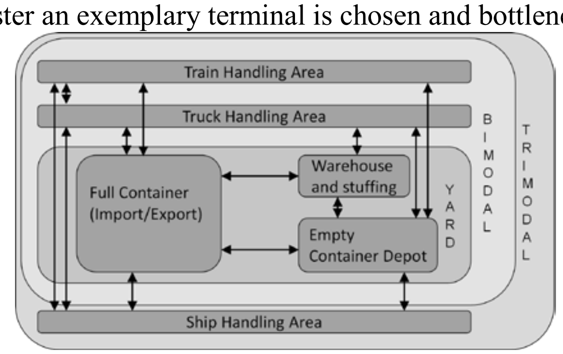

Figure 1: Container terminal material flow system (Böse 2007).

According to (Böse 2007), the logistical material flow system of a container terminal consists of different handling areas (see Figure 1). Containers are handled in the different handling areas for ship, truck and train. In the yard, containers are stored into the depot for full or empty containers. This is also the area for value-added-services (e.g. stuffing, repairing, etc.).

In container terminals, ground slots in the yard are allocated to a container by determining the shortest path from the loading point to possible ground slots or from possible ground slots to the target loading point, if it is known at the time of handling. A ground slot allocation always considers the ground slot restriction, which means 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 equipment. An allocation to other stacking zones or handling equipment can only happen if the stacking zone or the stack within the effective range of the handling equipment is full.

In inland ports, two possible ways to operate a container terminal exist: Either, all areas are handled in an integrated terminal with a Rail Mounted Gantry Crane module, spanning all areas, including up to five cranes on one track doing nearly all handlings. Or a mobile device (Reach Stacker or Van Carrier) transports containers between the areas. Inside the areas, the containers are handled by separated handling equipment or the mobile device.

In order to get detailed information about the container terminals, a container terminal survey has been created. The aim of this survey was to gain the most accurate information about the respective logistic system. This includes, in addition to general and system load data, information on layout objects, processes, handling equipment and operation strategies. Regarding the throughput of the terminals, the result show that all terminals located at the Lower Danube and most terminals at the Middle Danube handle less than 30.000 TEU per year. The container transport on the Danube is focused on the Upper Danube and is concentrated to Budapest and Györ at the Middle Danube, where the terminals handle between 30.000 TEU per year and 600.000 TEU per year. The results also indicate a correlation between the throughput and the layout of the logistic system of the observed terminals, so that the classification is based on the 'throughput' and the content of each class is the 'logistic system'. Regarding three different throughput scenarios, classes of three reference logistics systems for inland port container terminals were built. One container terminal in Enns (Austria) is operating in a completely different logistical system compared to all other terminals – hence, it was included as a fourth class. The assembled cluster is shown in Figure 2.

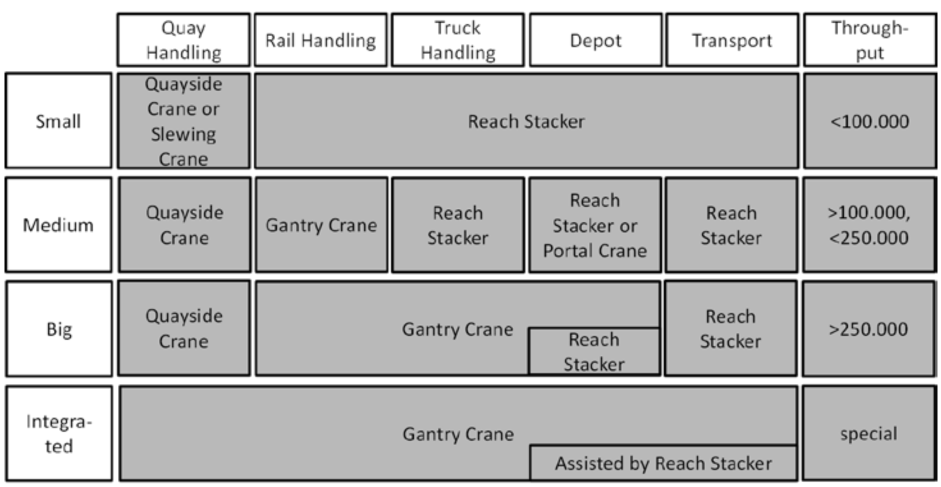

Figure 2: Cluster of logistical systems for container terminals alongside the Danube in TEU.

The cluster is composed of the four classes

- small (throughput smaller than 100.000 TEU per year),

- medium (throughput between 100.000 TEU and 250.000 TEU per year) ,
- large (throughput higher than 250.000 TEU per year) and the
- special integrated terminal concept.

In all small terminals, handling at the quay wall is either done with a gantry crane or a slewing crane. All other handlings are done with a reach stacker. Due to a low utilization, the handling equipment, especially the slewing cranes, are often shared with other terminals in the inland port. In medium size terminals, the handling of container vessels is done by quayside cranes. The transport of containers and the truck handling is done by reach stackers. To be able to handle the higher amount of containers, rail handling needs more rail tracks, so that it is necessary to handle the containers with gantry cranes. Furthermore, the container depot has to produce significant more container moves. This has to be handled with either a gantry crane, or an additional reach stacker. Unlike the medium terminal, the rail, truck and depot handling in big terminals is combined to a fast handling module operating all areas with a gantry crane module with one or more cranes on one track at the same time to raise productivity. Therefore, the large terminal consists of two handling modules, a waterside- and a landside handling module, with cranes and a transport system between these modules with reach stackers. The integrated terminal is the logistics system with the highest possible throughput. All handling areas and the depot are handled with a gantry crane module with one or more cranes on one track. During high peaks or for supplying external depot areas for empty containers, the logistics system is assisted by reach stackers.

As a result of the cluster analysis, every container terminal alongside the Danube can be assigned to a class representing a specific logistical system. This is the basis for a future improvement of the logistical system and design of infrastructural concepts for integrating NEWS into the transport chains at the Danube.

All small terminals alongside the Danube handle a maximum of 1500 TEU per year at the moment and are integrated into Piece-Good-Terminals, so that there are no gaps in the material flow at the moment. These terminals will be considered in future scenarios with a significant higher throughput and a new terminal layout concept.

In this paper we will show the work of the simulation solution with an case study of the terminal with the highest actual throughput. Due to this we will analyse one big size terminal regarding gaps in the material flow.

3 SIMULATION APPROACH

A state-of-the-art summary regarding operations and methods for optimization in the single subsystems of container terminals is provided by (Stahlbock and Voß 2007) and (Steenken et al. 2004). Furthermore a state-of-the-art summary regarding hinterland transport management is presented by (Acciaro and McKinnon 2013). The approaches include optimizations regarding yard planning, berth allocation problems, crane scheduling and transport planning. (Boer and Saanae 2008) present the sea port container terminals simulation and emulation CONTROLS. A heuristic analysis as a decision support for cranes and trucks in a container terminal is developed by (Van Hee and Wijbrands 1988). Furthermore, a lot of research was done, regarding the optimization of the storage areas in sea port container terminals. The approaches focus on improvements of the layout of the storage blocks ((Lee and Kim 2009), (Pettering and Murty, 2009)) or on stacking and reshuffling strategies ((Wan et al. 2009), (Park et al. 2010), (Park et al. 2011), (Choe et al. 2013) and (Van Asperen et al. 2013)).

Further research in container terminals focusses on terminal operations. A first discrete simulation model of stacking methods and strategies of cranes at their specific working area in sea port container terminals was presented by (Duinkerken et al. 2001). The coordination of terminal equipment was improved by (Chen et al. 2007) with a mixed-integer programming model. A decision support system for the berth handling in container terminals was presented by (Murty et al. 2005). They developed algorithms and models to minimize the berthing time and reduce the resource input as well as the storage utilization. A container sequencing for quay cranes with internal reshuffles is developed by (Meisel and

Wichmann 2010). (Gambardella et al. 2001) described a scheduling for loading and unloading operations in intermodal terminals and (Jung and Kim 2006) present a load scheduling algorithm for multiple quay cranes in sea port container terminals. An optimization model for gantry crane scheduling was done by (Legato, Mazza and Trunfio 2008).

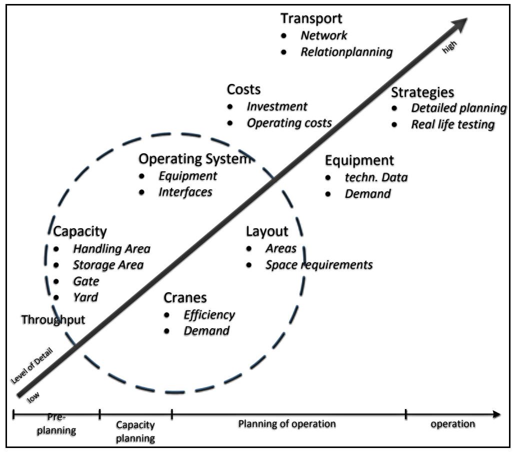

Figure 3: Planning tasks depending on the Level of Detail (Jürgen 2011).

According to (Jürgen 2011) the planning of a container terminal has to involve the steps described in Figure 3. During these planning steps, the information occurs with a different Level of Detail (LoD) starting with a low LoD during pre-planning and ending with a high LoD during the operation of the terminal. All the described approaches are optimizing terminal operations or operational planning and need a very high LoD with detailed knowledge about the processes and especially the control strategies of the handling equipment of a container terminals. However, during the NEWS project it is necessary to model future scenarios with new terminal layouts and logistic concepts in next steps of the project in a capacity planning for future demands. Furthermore, the simulation approach should enable the planner to detect bottlenecks in container terminals as early as possible during planning. As seen in Figure 3, the LoD for this planning tasks is low. Due to the non-existence of a simulation solution for a low LoD capacity planning of container terminals, we developed the simulation library TerminalSim for low LoD Container Terminals Simulation.

TerminalSim is based on the Logistics Suite of the simulation software "Enterprise Dynamics 8" from INCONTROL Simulation Solutions. It consists of parametrizable atoms representing functional elements of a container terminal with a high degree of abstraction. Due to this, one task is to define this functional elements in standardized modules along with reasonable parameter and key figures. In order to ensure a fast modelling and analysis of simulation scenarios, TerminalSim includes a standardized database pattern and a Visual Basic Application (VBA) to parameterize and analyze simulation scenarios. The work flow of the modules, databases and VBA-Analysis of TerminalSim is shown in Figure 4.

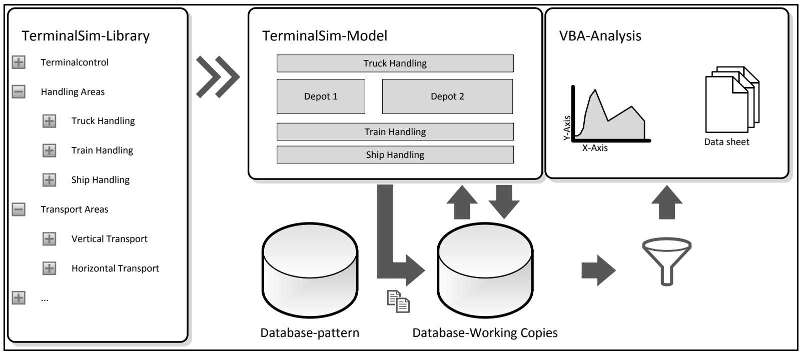

Figure 4: Work flow of TerminalSim.

The TerminalSim library includes all necessary modules to model an inland port container terminal. The modules are adjustable regarding their position, dimension, capacity and combination. A data generator provides input data based on variable input parameters. Some pieces of information are (more or less) known or can be predicted, like the number of ships and trains arriving and their approximate arriving time, size etc. For other data, like the arrival time of a truck or the storage period of a container, only statistical data can be assumed. The aim of the data generator is to produce a realistic, truck-based timetable in the following format: Truck *x* brings in container *y* on date/time *z* and *d* days later, it is taken by a ship/train (or the other way round). The created time tables are transferred to a Input Database and automatically loaded as a working copy of the database into the simulation model. During simulation experiments aditional sheets with results for each simulation scenario will be included into the database copy. Due to this, a VBA based analysis for each simulation scenario is possible after finishing the complete simulation experiments.

Table 1: Elements of TerminalSim.

Static modules	Dynamic modules	Logistic modules
Truck handling area	Container	Truck generator
Train handling area	Truck	Train generator
Ship handling are	Train	Ship generator
Transfer point	Ship	Analysis module
Container depot		Terminal control
Service area		
Gate		
Vertical transport		
Horizontal transport		

TerminalSim includes the modules shown in Table 1. The modules can be differed into static-, dynamic- and logistic modules and are based on the elements of the container terminal material flow system shown in Figure 1. The dynamic modules Container, Truck, Train and Ship passing through the static modules during a simulation run. Static modules represent functional areas and the handling equipment of the container terminal. In addition, TerminalSim includes the vehicle generators, an analysis module for the analysis of experiment results and a central terminal control module.

The TerminalSim modules have standardized interfaces to each other which are observed by the central control modules. These module contains the control strategies regarding the storage area and the handling equipment and acts as an interface to the Input Databases. In the yard, the containers are stored as near as possible to the handling area of the vehicle which collects the container. The handling tasks are sequenced in a list with a First-In-First-Out (FIFO) rule combined with the consideration of cut-off- and waiting times of vehicles in the sequence. These considerations represent the departure of a train or barge regarding to their schedule or a truck already waiting in the terminal. To secure the adherence to the schedule or to avoid long truck waiting in the terminal, the handling task will get a higher position in the sequence list the closer the time nears the cut-of-time or the waiting of trucks rises above 30 minutes. Due to this containers with only short time left for the handling or for trucks with a high waiting time will be preferred. The handling equipment handles always the task at the top of the list. All process times in TerminalSim are based on statistical distributions, which has to be entered by the user during the parameterization of the simulation model.

4 CASE STUDY

The simulation library TerminalSim is used to reveal gaps in the material flow of a big size container terminal located at the Danube regarding a possible rise in the throughput with the implementation of the NEWS ship.

The observed terminal is a trimodal container terminal, serving the transport modes road, rail and waterway. Handling 480.000 TEU in 2013, only 1% of the containers are distributed by ship. Therefore, 51% of the containers are distributed with rail with 12 block trains per day and 48% with trucks. In 2013, the percentage of full container handled in the terminal was 60% to 40% empty containers. The share of container sizes was 60% TEU and 40% FEU. In contrast to full containers, which remain 1 to 1.5 days in the terminal on average, empty containers remain in the terminal more than 15 days.

The container terminal consist of three different terminal zones. Zone 1 is a bimodal handling area for truck-train handling only. In this area, four rail tracks, one loading lane for trucks and a storage area are handled with three Rail-Mounted-Gantry (RMG) Cranes. Zone 2 is a trimodal handling area with two rail tracks, a mooring area for one ship, a loading lane for trucks and a storage area. The train handling area, the truck lane and the storage area are operated with reach stacker and empty etacker, whilst the ship handling area is operated with one RMG. Zone 3 is a flexible zone during peak times. In this zone, one rail track, a truck lane and a storage area are handled with reach stacker. Between the three different zones, containers are transported on demand with trucks.

The input data for the data generator is based on a survey conducted with the terminal operator. All process times and their statistical distribution are based on time measurements inside the terminal or on expert interviews and are without clearance for publications.

Based on this we mapped the terminal into a simulation model and thereupon validated the model by using the expert interviews conducted with the terminal operators.

5 RESULTS

The experiment to reveal gaps in the material flow is based on the actual situation of the observed terminal with the scope presented in section 4. The development of new terminal concepts are part of subsequent research. The experiment was simulated 20 times to avoid statistical runaways. The simulation time was 15 days and each day has20 operating hours, so that the overall simulation time was 300 hours. To avoid along warm up period, we calculated a starting condition of the terminal, consisting of all export and import containers which are handled on the first days. Due to this we don’t need to consider a warm up period.

Analyzing the results, two mayor gaps in the material flow can be identified. The storage areas in the whole terminal and the handling cranes in Zone 1 of the terminal. The storage areas are located in the terminal as followed:

Table 2: Location of storage areas.

	Zone 1	Zone 2	Zone 3
Export:	Area 1 Area 2 Area 3		Area 11 Area 13
Import:	Area 4 Area 5 Area 6 Area 7 Area 8		Area 12
Empty:		Area 9 Area 10	

As shown in Figure 5 the utilization of the storage areas for export and import containers are very high during the simulation runs.

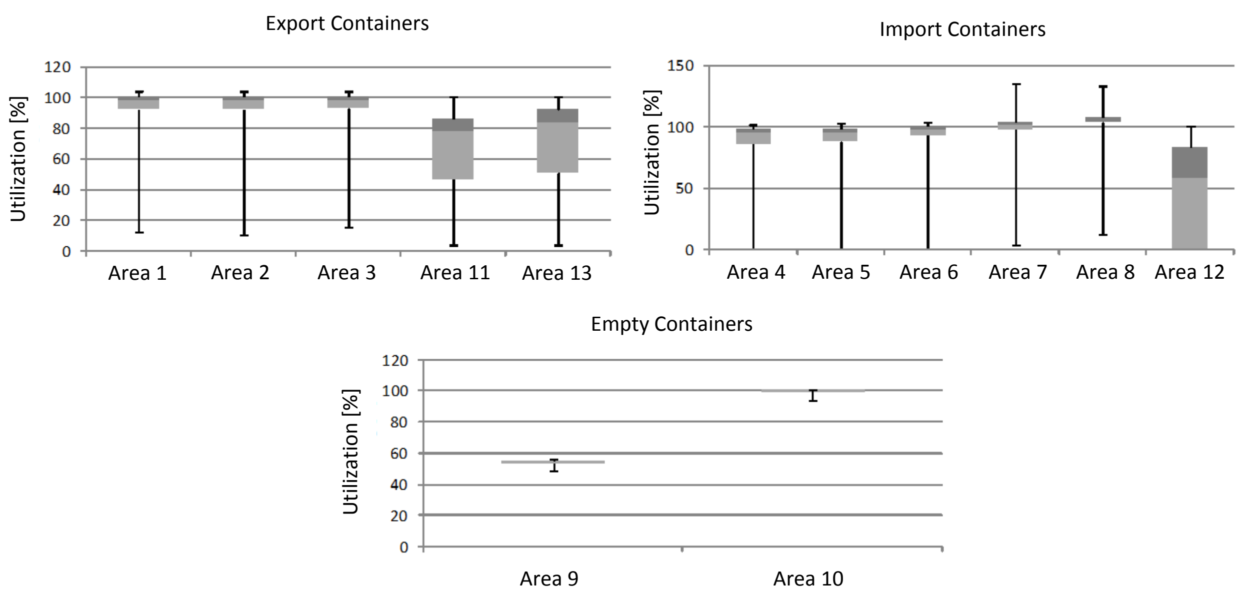

Figure 5: Utilization of Storage areas for a) export -, b) import - and c) empty containers.

For export containers, only Area 11 has an average utilization under 80%. This area is located in Zone 3 of the terminal, which is only considered in peak times. The areas for Export containers in Zone 1 are utilized between 80% and 100% and provides no space to increase the throughput significantly. For import containers, area 12, which is only considered in peak times, is utilized very low. Only in average 60% of the area are needed, the rest of the area can be assigned to other modes of transport. All other areas for import container are utilized between 80% and 110% and also provide no space for a growth in throughput. The possibility to stack more than 100% into storage areas is include to avoid deadlocks in the simulation. This is also an indicator that these storage areas are operated at full capacity and needs to be expanded. Hence, it is necessary to create new areas for export and import containers, which is part of the future work of the research project. For empty containers the Area 9 has an average utilization of 55% and provides enough free space to handle containers.

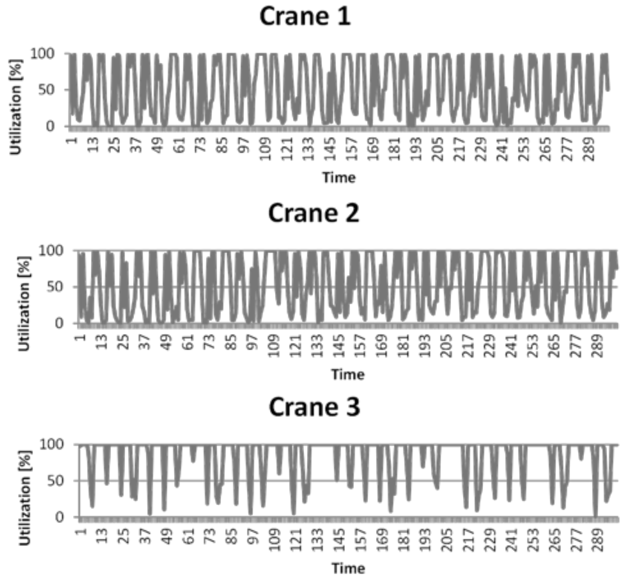

Figure 6: Utilization of cranes in the terminal Zone 1.

The utilization of the three cranes in Zone 1 of the terminal alternates strongly and depends on the arrival of block trains in the terminal. In peak times the utilization of every crane is 100%. In this time the cranes handle containers from and to trains and to trucks at the same time. To secure the adherence to schedule of the trains, handlingtasks from and to trains has to be operated as fast as possible. The time slot for these handlings is only 3 ½ hour. This leads to a high average stay time of the trucks in the terminal. As shown in Figure 7 the average stay time is 4886 seconds (81 minutes). It should be lowered to a value between 1800 and 3000 seconds because in interviews conducted in an earlier project, forwarders indicated these numbers as cut-off times, where they consider to switch the containers to other terminals.

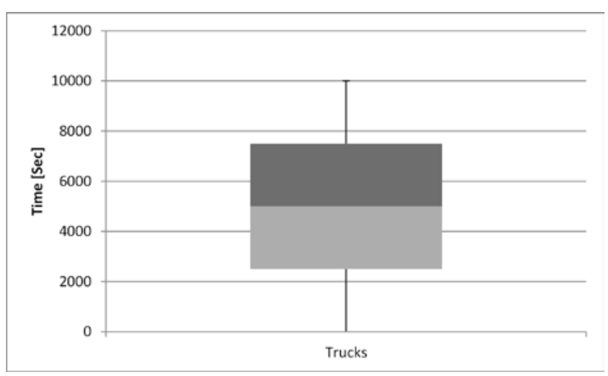

Figure 7: Average Stay Time of trucks in the terminal.

To lower the stay time, it is necessary to analyze the benefits of including a crane to Zone 1 of the terminal. This is part of future work in the research project and is not shown in this paper.

Another gap in the material can become the inter terminal transport between the different terminal zones. At the moment this is not a huge factor, because the containers are directly stored in the zone of the arriving train and inter terminal transport only occurs in peak times. But with a predicted and planed rise of container handlings with ships, a rise of handlings from the ship to a train and vice versa will occur.

Due to this, the inner terminal transports will rise significant. This has also to be proved in future scenarios.

6 CONCLUSION

This paper showed that using low LoD simulation in the early stage of new planning or expansion planning of container terminals enables the terminal operator and planner to reveal gaps in the material flow in an early stage of planning. Furthermore, they can conform their planning steps and can test new strategies in a virtual model, without cost-intensive real time tests. The low LoD simulation gives the possibility of a fast and cost efficient modelling of a container terminal.

As a next step we will use the simulation to reveal gaps in reference ports in the other throughput classes. After that new logistical concepts for the terminals for a significant higher throughput especially for ship handlings will be planned with the use of the low LoD simulation. The simulation enable the planner to detect bottlenecks in container terminals as early as possible during planning and reduces cost intensive adjustments in a later planning steps.

ACKNOWLEDGMENTS

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