Simulation-Based Analysis of Storage Strategies for an Inland Container Terminal

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Abstract. Due to the transformation of the logistics sector, the use of trimodal container terminals is becoming increasingly important. This results in major challenges, such as managing the constantly increasing volume of shipments while simultaneously improving the efficiency of internal processes.

Adapting existing storage strategies has proven to offer great potential for raising productivity.

In this context, the following paper develops an alternative storage strategy for container terminals. For evaluation of its functionality, a simulation model for an exemplary trimodal container terminal is developed. In addition, potential is analysed, based on comparison with the currently used storing strategy.

Introduction

The logistics sector is important to the economies worldwide and e.g. the third-largest economic sector in Germany with a total volume of € 293 billion in 2021. Logistics service providers such as transportation and handling account for 50% of this [1]. Despite it´s economic importance and impressive figures, the logistics sector is facing major challenges.

Logistics has to fulfil customer requirements in an increasingly volatile environment and has failed so far to achieve sustainability targets. One lever in this respect is modal shift from road to combined rail-road-transport. A forecasted growth of rail by 73% by 2030 compared to 2010 in Germany is particularly attributable to rail/road trans-shipment as a key growth driver [2].

With freight transport accounting for 19.4% of Germany's total greenhouse gas emissions in 2021 [3] modal shift and other measures to reduce emissions are vital and operators of trimodal container terminal connecting road, rail, and water modes of transportation in container freight transport are in need of solutions to cope with growth efficiently.

One approach to overcoming these challenges for a trimodal container terminal is to improve internal processes. These range from improving the storage strategy to developing additional space and optimizing the use of resources. However, new strategies need to be tested before they are applied in reality. One method that makes this possible is simulation. Simulation makes it possible to create a virtual image of reality in order to test changes based on this image, which can then be transferred to reality [4].

In order to support those which facing these challenges, this paper aims to demonstrate the possibilities for optimizing operational strategies using simulation. Therefore, an exemplary container terminal is presented, which aims to compare two storage strategies by using simulation. The storage strategies to be compared differentiate as follows: the current situation with storage exluding the removal path, and the target situation with storage close to the delivery points.

For this purpose, our paper is divided into five sections. After a brief overview on current research on simulation for operational strategies of container terminals, the used simulation procedure is presented. Followed by developing the simulation model and conducting related experiments, an outlook on future work in this field of research is given.

1 Literature Review

A systematic literature review based on the guidelines of Durach et al. [5] is conducted to evaluate the common use of the method for planning operational strategies of container terminals.

The following search terms and combinations of these are used to identify relevant sources: “simulation”, “optimization”, “container ter-minal”, “stack”, “strategies”, and “terminal operation”. Publications from the databases Scopus, Web of Sci-ence, Google Scholar, and Science Direct are examined for this purpose.

After full-text analysis, 18 results emerged. The evaluation of the results shows that the methodological approach of simulation is used for optimizing operational strategies. However, no publication was found that deals specifically with the storage strategies. In a related study, Clausen et al. [6] constructed a simulation model to identify the optimal operational configuration for a terminal. The model determines the most effective combination of crane control and resource management strategies for each load the terminal can accommodate, based on a specific set of operational conditions. Novaes et al. [7] examine in their study the potential of data science to enhance container terminal operations, improve efficiency, boost throughput, and strengthen competitiveness in the shipping sector. Decision-making within container terminals, particularly in determining optimal container stacking locations, is a significant challenge due to the multitude of factors at play. By analyzing the datasets, new strategies and policies can be simulated to minimize container rehandling operations.

Overall, the papers identified indicate that simulation has applications in a variety of use cases in the area of planning the operating strategies of container terminals. For this reason, the simulation method is described below before the model developed for this use case is presented.

2 Method

“Simulation is the representation of a system with its dynamic processes in an experimentable model with the aim of reaching findings which are transferable to reality” [8]. To examine a system with simulation in a struc-tured manner, multiple procedure models can be used (e.g. [4], [9], [10]). The procedure models provide users with information for appropriately carrying out simulation studies. In german-speaking countries VDI Guideline 3633 Sheet 1 is widely used and selected for this study because the system under investigation is located in Germany. The associated Verification and Validation (V&V) during the study follows Rabe et al. [11]. Their procedure model for V&V aligns with the phases of VDI 3633, which makes its application suitable for this study.

The phases defined by VDI 3633 guide users from task definition to the experiments and analysis. Within the procedure, there is a clear separation between data and model and each phase produces a result [4]. The intermediate results are the subject of the V&V. According to Rabe et al. [11], each phase is examined in itself and additionally with respect to or against previous phase results [11].

3 Simulation Modeling

According to the introduction, the objective is the analysis of a given storage strategy for container handling and its comparison with a zoning strategy. The investigations are conducted for two inland container terminals. CT1 is trimodal (see Figure 1) and CT2 is bimodal. CT2 contains a road and a rail lane, which are located next to each other. Prior to the actual strategy comparison, the preliminary goal is to model the terminals in their respective system state with sufficient accuracy. The subsequent comparison is aimed at the container movements and therefore focuses on the internal handling processes. Accordingly, the system under consideration ends with the entry and exit of transport vehicles.

For this study, CT’s activities are roughly divided into three handling processes. Incoming containers are stored and they are retrieved to leave the terminal. Additionally, a relocation process may be necessary for stacked containers. Containers enter the system by a mode of transportation (train, truck or ship).

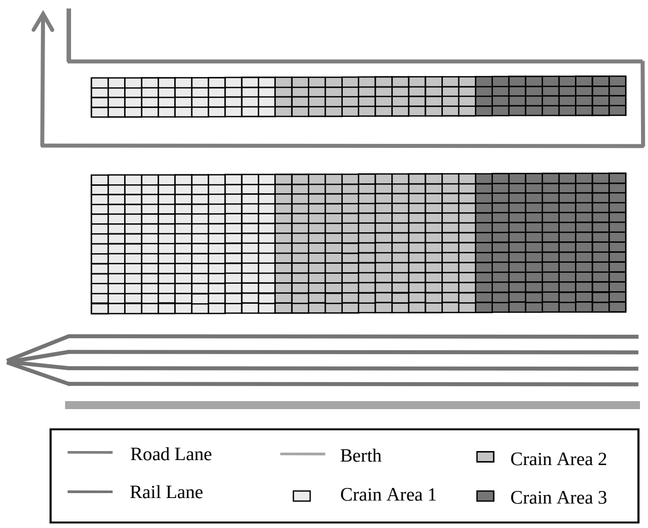

Figure 1: Schematic representation of container terminal 1.

For this study, CT's activities are roughly divided into three handling processes. Incoming containers are stored and they are retrieved to leave the terminal. Additionally, a relocation process may be necessary for stacked containers. Containers enter the system by a mode of transportation (train, truck or ship).

Within the storing process, firstly a given strategy determines the position. Thereafter, a handling resource (e. g. portal crane) moves the container to its destination. The retrieval begins with the mode of transportation arriving at the terminal. The time of arrival may be known with a containers arrival or is defined while the container is already stored. Before moving the container it is checked if the container is movable (i. e. the container has no containers stacked above itself). Movable containers get loaded onto the mode of transportation and leave the system. For non-movable containers the relocation process for the container above is initiated before moving the desired container. At the beginning of the relocation process, it is also checked whether the container is movable. For movable containers the position get determined by the given storage strategy. For non-movable container the relocation process gets initiated for the container above and the desired container gets moved afterwards. Accordingly, the relocation process is recursive. For this study, we only consider relocations because of retrieval processes.

The handling resources, containers and modes of transport are being modeled as agents, which define their behavior within the terminal. The model including the described processes and agents is implemented with the simulation software AnyLogic 8.9 as a discrete event simulation using agents.

4 Experiments & Results

Within the experimental framework, the current terminal is analysed in the first simulation scenario using five different degrees of capacity utilisation with varying numbers of in- and outbound transport vehicles and containers. The second scenario implements the developed storing strategy with three different weighting factors. In order to achieve valid results, the confidence interval method is used to determine a number of 30 replications to be carried out per parameter variation. The duration of each simulation run lasts seven days with a two-day transient phase regarding to the method of Welch [12].

The developed storage strategy follows the existing requirements for container storage. Currently, the optimal storing location is identified based on the distance from its current position and under consideration of time restrictions such as the retrieval date.

Additionally, the new storage strategy also takes into account the distances for retrieving containers. For this purpose, the storage area is divided into various sections running along the road and rail lanes. According to this, the optimal storing location can be determined in order to ensure the shortest possible retrieval distance to the lanes. Therefore, our calculation is characterized by three elements. "A" indicates the distance of the container's current location to the available storage position and "B" represents the direct retrieval distance to the lanes of truck and train. In addition, weighting of the retrieval distance is managed by factor "p".

$$StoringPosition\_Weighted = A + p * B \quad (1)$$

For validation of this equation, its functionality is verified in the simulation model. For this purpose, the straight distance between retrieval containers and the lane of truck and train is analysed. Since ships are mostly used for delivery of the containers, this mode of transport is not taken into account in the evaluation.

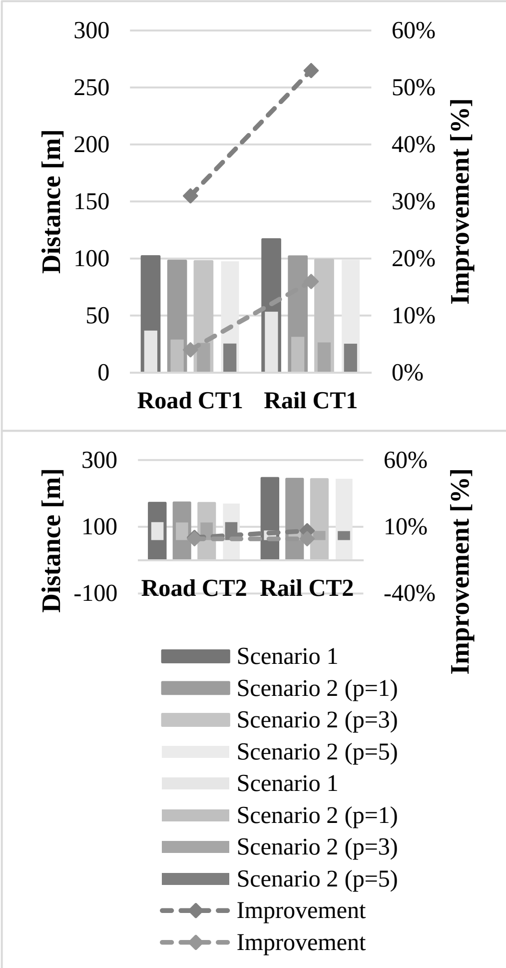

Figure 2: Comparison of covered distances for container retrieval.

From the grey-coloured bars in Figure 2, it can be observed that covered distances for retrieval at CT1 decreases for all weighting factors when applying the storing strategy compared to initial scenario 1. Depending on the mode of transportation, this improvement amounts to 31 % respectively 53 %, as shown by the grey dashed line. The improvement for CT2 is less significant. In general, containers are stored closer to the retrieval area, thus indicating that optimisation of the storing position by the equation works.

For a complete evaluation of it's potential, the real distance from containers to the transport vehicles must be analysed. This is shown by the green bars in Figure 2 and indicates that the real distance is significantly greater. Furthermore, the green dashed line demonstrates that the improvement achieved compared to scenario 1 is not as great as previously suggested. At CT2, this positive effect is almost neutralised.

Furthermore, the total duration of dispatching processes for trucks and trains at both terminals will be analysed to validate the potential of the new storing strategy. However, at either location there has been no significant reduction for both modes of transport. For some scenarios, dispatching times have even increased.

Overall, results of the simulation scenarios indicate that the new storing strategy does not significantly improve internal processes of the container terminal. Due to a high utilisation of the lane, trucks can only stop in an assigned area but not at the level of containers storage location.

Although containers will be placed closer to the lane, it will not affect its distance to the real loading position of the truck. This difficulty also occurs when loading the trains, as each container is linked to a fixed railway wagon, which may not be positioned at the same level as containers storing location.

5 Conclusion

In this paper, two different storage strategies have been compared with focussing on increased productivity in a trimodal container terminal. To evaluate their potential in practice, simulation has been used. On the basis of VDI 3633 a simulation model was developed, which combines agent-based and discrete-event simulation. Evaluation based on industry-specific key performance indicators revealed that our newly developed storing strategy is working effectively and can improve internal processes.

However, due to specific infrastructural and operational conditions of both terminals considered in this example, the expected improvement can not be achieved. In order to fully realise its potential, further work must be conducted to apply the storing strategy in combination with scheduling of incoming modes of transportation. In addition, this strategy must be modified depending on the use case and its infrastructural conditions.

References

[1] BMDV: Masterplan Binnenschifffahrt. 2018.

[2] Boysen J. et al.: Status quo des Güterverkehrssystems in Deutschland – eine Metastudie unter besonderer Betrachtung der Vernetzung des Verkehrs.

[3] The Umweltbundesamt: Emissionen des Verkehrs. 2023.

[4] VDI Association of German Engineers e.V.: Simulation of systems in materials handling, logistics and production: Part 1(VDI 3633). Berlin: Beuth, 2014.

[5] Durach CF, et al.: A New Paradigm for Systematic Literature Reviews in Supply Chain Management. J Supply Chain Manag, 53 (4) 2017, p. 67–85. DOI 10.1111/jscm.12145

[6] Clausen U, et al.: CONTSIM–Container Terminal Management with Simulation. Procedia - Social and Behavioral Sciences, 54 2012, p. 332–340. DOI 10.1016/j.sbspro.2012.09.752

[7] Novaes MT, et al.: Operational performance evaluation of a container terminal using data mining and simulation. Asian Transport Studies, 10 2024, p. 100127. DOI 10.1016/j.eastsj.2024.100127

[8] VDI Association of German Engineers e.V.: Simulation of systems in materials handling, logistics and production: Terms and Definitions (VDI 3633). Berlin: Beuth Verlag, 2018.

[9] Law AM. Simulation modeling and analysis. New York, NY: McGraw Hill Education, 2015.

[10] Banks J (ed). Handbook of simulation: Principles, methodology, advances, applications, and practice. New York: Wiley, 1998.

[11] Rabe M, et al. A new procedure model for verification and validation in production and logistics simulation. In: Winter Simulation Conference, 2008 (Editor: S. J. Mason). Piscataway, NJ: IEEE, 2008, pp 1717–1726.

[12] Welch PD. The statistical analysis of simulation results. The Computer Performance Modeling 1983, 1983:268–328.

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