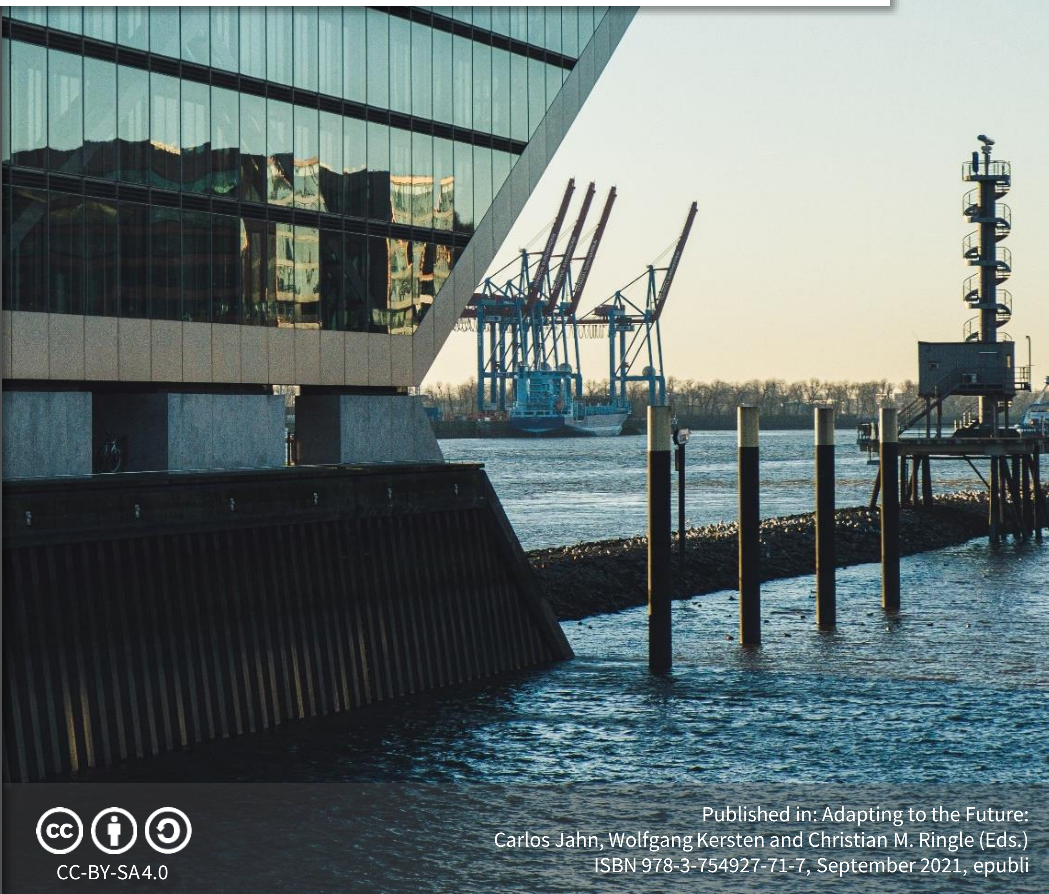
Proceedings of the Hamburg International Conference of Logistics (HICL) – 32

Stephan Krüger, Anne Schwientek, and Carlos Jahn

Evaluation of an Integrated Planning and Simulation Tool



Published in: Adapting to the Future:
Carlos Jahn, Wolfgang Kersten and Christian M. Ringle (Eds.)
ISBN 978-3-754927-71-7, September 2021, epubli

Evaluation of an Integrated Planning and Simulation Tool

Stephan Krüger[1], Anne Schwientek[2] and Carlos Jahn[2]

1 – MLS Institute of Maritime Logistics

2 – Hamburg University of Technology

Purpose: *For new planning or redesigning of existing logistical nodes it is important to use areas and technical equipment for handling, transport and storage as efficiently as possible. Layout planning and logistic simulation are used separately in the development and planning of logistic nodes. In the field of combined transport facilities, planning is in most cases limited to the static layout according to common parameters by classical planning instruments.*

Methodology: *By applying the ISI-Plan tool the layout and configuration of an existing inland terminal is parameterized and implemented via the surface visTABLE®. Consequently, the arrangement of infrastructure modules such as storage blocks, lanes and tracks are modelled. The same applies to the superstructure used.*

Findings: *The functionality of combining both methods via one interface could be demonstrated. Due to the complexity of the terminal which was reflected in high computing times, it was necessary to work with a downscaled model in order to obtain performance statements.*

Originality: *The innovative ISI-Plan application makes it possible for the first time for a wider spectrum of operators of logistics nodes to analyze, evaluate and modify the prevailing situation in an uncomplicated manner. Compared to conventional procedures, it is possible in a significantly reduced scope of time.*

First received: 20. Jun 2021 Revised: 18. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

In response of growing challenges regarding an increased throughput in less time and higher quality there is a need for continuous evaluation and adaptation of internal operational processes at logistic nodes in ports and the hinterland. Due to the increasing complexity and rising handling figures container terminals (Stahlbock and Voß, 2008) and inland terminals (Khaslavskaya and Roso, 2020) are a prime example of this. When it comes to new planning or redesigning of existing logistic nodes it is therefore fundamental to use the available space and the technical systems used for handling, transport and storage as efficiently as possible. In particular for assuring and optimizing solutions for commonly planning logistic processes and in specific for container terminals, for seaports as well as inland terminals simulation is the key. By combining static layout modelling and its simulation via an interface, modifications in the terminal configuration can be analyzed with little effort in contrast to conventional methods. Up to now, the consideration of an integrated layout planning for logistic nodes has not been done from an academic point of view. The term “terminal” covers not only seaport terminals but also locations for multimodal transshipment in the hinterland of the ports (Notteboom et. al, 2021). Especially for operators of inland terminals there is the chance to reduce the planning and modeling effort for adaptations and new planning. Therefore, this work refers to inland terminals. This leads to the underlying questions in this thesis: How can the two tools be efficiently linked to analyze inland terminals? In the following part, first more theoretical background knowledge about terminal design and simulation software is given. In section 3, the methodology is elaborated. This is followed by the presentation of the results in Section 4 and their discussion in Section 5. Finally, conclusions are drawn in Section 6.

2 Theoretical Background

So far, planning and optimization by means of terminal simulation (Dragovic et al., 2017; Angeloudis and Bell, 2011) has taken place separately from each other. Static terminal layouts (Böse, 2020; Brinkmann, 2005), which are based on standard layouts, empirical values or calculations, serve as the basis of a simulation study. The simulation study then offers possibilities for evaluation and further adaptation of the terminal design to be tested. However, the creation of the simulation models in particular requires extensive software knowledge and time. Subsequently, one or more further adaptation steps would be required for the static terminal layout under investigation, which in turn would result in high workloads and personnel costs.

Object-oriented modelling enables the representation of real systems. For this purpose, an element of a real system is provided with certain changeable attributes. The more complex and realistic the environment, the higher the number of attributes to be adjusted must be. In particular, the modelling of large systems with a large number of attribute states is time-consuming and accordingly complex. They are nevertheless useful for providing answers to specific questions in terminal layouts. Common modelling tools offer predefined functions, but they must be adapted to the models created by reprogramming objects or programming individual scripts and therefore require trained users.

There are simulation models created specifically for container terminals that focus on medium to large overseas ports as a unit. However, they do not meet the requirement of versatile usability as it would be necessary for inland terminals and intermodal terminals, because multiple decision variables, static and dynamic constraints and risks come into play especially in the planning of the mentioned logistic nodes. Therefore, specifically in the simulation of container terminals in seaports, the focus is on selected areas as shown by Nourmohammadzadeh and Voß, 2021; Tan et al., 2021; He et al., 2015; for container gantry cranes or Yu et al., 2021; Kastner, 2021; Gharehgozli et al., 2017 and Kemme, 2012; for automated storage blocks.

Furthermore, software solutions exist that combine planning and its simulation in approaches. In material flow planning (Wurdig and Wacker, 2008) and production planning (Toth et al., 2008) this approach is considered. Only Schwientek et al. (2018) address how the conceptual framework for developing an integrated layout planning and its simulation can look like. The approach consists of the development of an integrated modelling and simulation environment for terminals, which is based on the planning software visTABLE® and the simulation software Enterprise Dynamics®.

Despite many possibilities of innovative layout planning software, this analytical or static approach cannot consider the container handling processes of the terminal. Thus, it not possible to check the defined functional areas and the equipment for adequate capacity, e.g. to cover possible peak loads or to identify bottlenecks. If this is to be investigated in advance and as accurately as possible, simulation software can be used to dynamically model the terminal.

Up to now, the actual planning of the layouts and the corresponding simulation have mostly been decoupled from each other and carried one after the other. As a result, adjustments to the layout based on the simulation results lead to several optimization iterations, which is both time-consuming and causes high personal costs in the planning process. This paper describes with the development of an integrated software tool which allows the user an intuitive and simple layout planning adapted to individual conditions. At the same time, an automatic simulation of the created terminal layout is carried out and provides the basis for a performance analysis.

3 Methodology

To answer the research question of how a static planning tool and a dynamic simulation tool can efficiently be linked, the approach of an integrated solution was chosen in this paper. By implementing the terminal, statements can be made about the KPI of the terminal.

The methodological procedure is as outlined in the following. At first the interface is examined in more detail with regard to its mode of operation, which represents the basis for communication between the frontend and the backend. This is followed by an explanation of the data generation and parameterization by the frontend and the transfer and implementation in a simulation model to the backend.

Based on terminal visits and interviews with various domestic terminals, as well as extensive literature studies, the requirements for the integrated software solution were defined. A concept was then developed for integrating the two applications of the software houses, which had already existed independently for several years, in order to meet the previously defined requirements.

The case study approach is particularly useful when it comes to taking an in-depth look at a problem, event or phenomenon of interest in its real-world context. Therefore, a very classic structured inland terminal, hereinafter called terminal, is used to validate the software application. For this purpose, the terminal layout is created via the visTABLE® graphical interface, in which all relevant data are entered. An executable model is then generated in the Enterprise Dynamics® simulation software via the XML interface. Since simulation models always represent an abstraction of the real prevailing conditions, the integrated planning of terminals and their simulation does not claim to be optimal. Rather, it represents a basis for comparison of further simulation runs. In order to obtain information about the performance of a terminal, variations of a layout are always necessary.

This publication concentrates on the evaluation of the performance indicators handling units, loading units on the terminal, utilization of the terminal areas and utilization of the terminal areas.

3.1 Program Interface

The integrated software tools principle of operation can be seen in the following

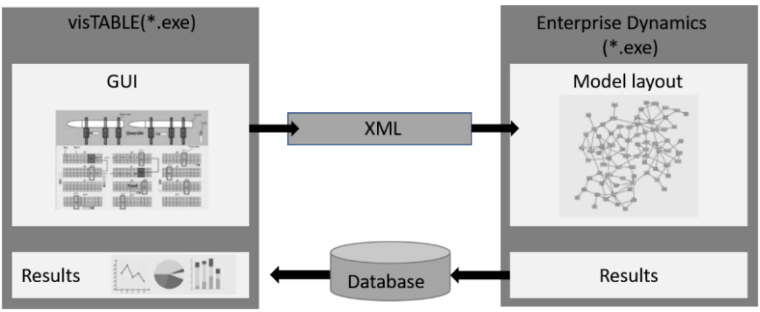


Figure1.

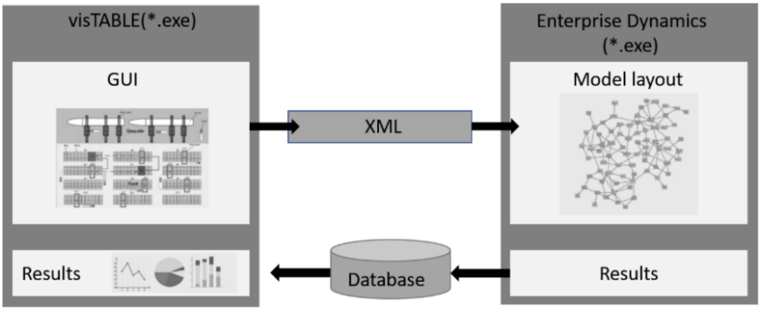


Figure 1: Interface concept

The interface forms the communication basis for both software applications. It is used to transfer all layout and user data, in particular the parameterized components of the layout plus general model parameters and the selection of target variables to be measured. At the same time, it is used for fine control of the simulation. Another interface is used to transfer the raw data generated by the running simulation and also the accumulated result data for presentation in the graphical user interface. Interposing a database for the recording of simulation data has the advantage that the frontend and the backend can act independently of each other. Another advantage is the dynamic determination of the quality of target variables, because as a rule, stochastic parameters become more accurate as the runtime of a simulation increases.

3.2 Frontend

With the help of visTABLE®, terminal layouts are created, designed and parameterized for the realization of the dynamic simulation. To simplify handling, satellite images can be uploaded as a basis for planning in order to place true-to-scale elements. A model library is available for the design and determination of the spatial structure of the terminal, which contains the most important arrangement objects. These include roads, tracks, storage areas, but also crane systems. Furthermore, there are also objects that change location, which are not defined by placement in the layout, as they change their location dynamically during the runtime of the simulation.

3.2.1 Basic Features of the Terminal

The determining properties and performance parameters necessary for planning the terminal must be defined in advance of the simulation.

The loading unit mix indicates which shares of the handled loading units are to be assigned to a specific loading unit type. The specification of these parameters defines for which loading units (types) handling orders are dynamically generated at runtime of the simulation There are five defined loading unit types (20-foot, 40-foot or 45-foot container, swap bodies and trailers).

The cycle time determines the cycles in which the schedules are regularly applied. In this way, planned closing days of the terminals can be considered.

The modal split results from the transshipment volumes for each combination of transport modes.

The value of the global transshipment serves as a validation parameter after the simulation runs. This parameter is used to describe the target global throughput (in TEU) per year. By comparing this parameter with the value achieved in a simulation run(in the respective time slice), it can be determined whether the required performance of the terminal has been achieved.

Furthermore, the parameter Gateway defines the loading units in the terminal that are handled and transported directly between the mass transport means of inland waterways and rail. The share of direct loading describes the parameter that includes all directly handled loading units from one mode of transport to another mode of transport, which means no intermediate storage.

3.2.2 Timetables and generation of order data

The simulation generates handling orders during run time. For this purpose, the simulation generates order data based on fixed timetables as well as on parameters from the modal split and load unit mix, which should simulate a typical operation of the planned terminal as realistically as possible.

Timetables for the rail mode are defined by specifying specific arrival and departure times. They are therefore not generated randomly by the simulation, but are generated repeatedly on the basis of fixed timetable data according to the defined cycle.

A timetable entry is to be defined for each planned transshipment of the mode of transport ship if this transshipment is planned and takes place regularly. Arrival and departure are to be defined analogous to the railway timetables.

In contrast to the schedules of the rail and ship modes of transport, no fixed schedules are defined for trucks. The order data of the transshipment orders are determined by the simulation at runtime from various parameters. The terminal parameters global modal split, share of gateways, share of direct transshipments are used.

3.2.3 Equipment

Mobile equipment is not defined by the placement of specific models or objects in the layout, since the equipment is not in fixed positions. Equipment in this sense includes all means of transport that can actively move on the terminal itself and are used for the transport of loading units. For this purpose, not each individual instance (e.g. of a reach stacker) is recorded, but the quantity of all equipment of the same type is described collectively. During the simulation run, it is dynamically selected whether and which concrete instance of a piece of equipment is used for a handling or transport order. The simulation calculates and uses the shortest route for the selected equipment, considering existing restrictions.

The mobile lifter is equipment that can move loading units vertically and is thus able to load and unload means of transport and horizontal transport. In principle, they can move freely on the terminal (subject to restrictions). The stacking height and the time required for a complete lift of load units can be specified so that during the simulation execution the time required to move a loading unit is determined dynamically based on the position of the loading unit.

Horizontal transporters are objects of the handling equipment that can only transport loading units horizontally. Horizontal handling systems are especially solutions for the increasing transport demand of non-craneable semi-trailers by rail. At the time of simulation, all instances of a horizontal transporter move constantly over the terminal at the specified speed.

3.2.4 Module Library

There is a manageable number of models available for the representation of the terminal, with which the layout and simulation model are described. These are, on the one hand, objects that are essential for the structure and behavior of the terminal and carry parameters, and, on the other hand, objects that are more of a visual aid for a realistic representation of the planned terminal and do not have to be parameterized. These objects, also called arrangement objects, are stationary resources of the terminal and have a parameterizable position and physical extent.

Terminal surfaces divide the terminal layout into rectangular areas with different functions. Terminal areas can be logically connected to each other and thus form a network on which means of transport can move. Relationships can exist between the arrangement objects that result solely from the relative position of the arrangement objects to each other.

Yards have a buffer function as intermediate parking areas. They are defined by rectangular areas in which parking spaces for loading units are created in regular structures and addressed by the simulation.

A berth is used for the selection of dedicated terminal areas to entries of the ship schedule. The following applies to the positioning of a ship along the quay wall: A quay edge is defined for ships. Only a fixed allocation can be made, otherwise the simulation randomly selects an available mooring at runtime.

During the simulation, a road network is built automatically. This is done on the basis of the relative position of the roads to each other.

In the model library you will find predefined tracks for half trains (48 20-foot containers à 1 TEU) and full trains (96 20-foot containers à 1 TEU).

The working area of cranes is not defined by the physical model of the crane itself, but by its crane track. This is how you define the area in which a crane is allowed to operate. Cranes can generally handle loading units of all types. Various parameters are available for defining the technical capacity of the crane.

3.3 Backend

The software application makes it possible to transfer a static layout from the frontend directly into a functional dynamic simulation model with stored logistics strategies in the backend.

3.3.1 Layout Design and Path Network

The automatic generation of the static terminal layout created in the frontend is made possible by the fact that each object in the simulation model has all the necessary geometric information. This makes it possible to unambiguously determine the position of each individual object in the plane of the terminal. In addition, the terminal surfaces contain information about whether they can be driven on, who is allowed to drive on them and how they are connected to each other.

From this data, a route network can be generated for each means of transport, which on the one hand contains all terminal areas that can be reached by the means of transport and controls the movement of the means of transport on the terminal site. In order to be able to represent the transport processes in the simulation model, a simple algorithm is sufficient to search for connected routes between a start and a destination node of the route network. If the path from a start node to a destination node exists, the shortest path is selected.

3.3.2 Strategies and Object Relations

In addition to the functionality of the objects, which defines the elementary activities such as loading and unloading, driving, etc., the object behavior is essentially controlled by strategies, which always come into play when there are several options for proceeding at a decision node, e.g. when selecting the next handling order, the suitable equipment and the suitable loading unit (Kaffka et al., 2014; Clausen and Kaffka, 2016; Eckert et al., 2013). The strategies are firmly linked to the simulation logic and are therefore implemented in the backend. The user can only select the strategies for a given decision criterion in the frontend.

Since the terminal is analyzed at the loading unit level, the overall state of the terminal changes as soon as the relationships of the objects used to each other change, i.e. positions or number, of the loading units are modified. This happens when means of transport arrive and depart and when loading units are repositioned on the terminal premises. Repositioning is defined as follows:

- Picking up the loading unit from a means of transport, a horizontal transport or a terminal area.
- Optional transport of the loading unit to another position on the terminal site.
- Setting down the loading unit on a means of transport, a horizontal transport or a terminal area.

This results in several processes that cause a change of state of the terminal:

- Arrival and departure of means of transport
- Loading and unloading of means of transport
- Loading and unloading of loading units (this also includes parking and picking up of loading units on any terminal area or in the same terminal area (restacking))
- Internal transport of loading units
- Checking whether ready for departure (checker/inspector)

In contrast to incoming and outgoing transshipments, which always involve a longer stay on a terminal area, direct transshipments are transported by the equipment directly from one means of transport to another. If both means of transport are of the ship or train type, this is referred to as a gateway. Basically, for each incoming mode of transport containing loading units to be transshipped, a transfer order is created for the equipment for each of these loading units. Destinations are not yet determined, but only when a piece of equipment reports itself as ready. The system then checks whether direct transshipment is possible. This is the case if another carrier has been announced in time or is already on the premises. In order not to transship all loading units directly as soon as the opportunity arises, a weighted distribution is used to select whether a direct transshipment should actually be carried out. The weighted distribution considers all loading units that have already been transshipped up to that point and adjusts the proportion of direct transshipments to the default defined by the user.

3.3.3 Simulation of Terminal Processes

The processes that take place in the terminal are presented below. A process is triggered when a change of state takes place. The conditions for a change of state are defined.

The object class Equipment includes the subclasses MobileLifter, Crane and HorizontalTransport. Even if individual functionalities are executed differently (e.g. travel or handling), the states for the objects involved are basically the same. Each piece of equipment follows the same repetitive sequence: Drive to the pick-up location of a load, pick it up, drive to the drop-off location of the load and drop it off. It is assumed that the source of the load is at the pick-up location before the corresponding order to pick up the load is generated.

The object class means of transport contains the three modes of transport truck, train and ship. While the last two are exclusively passively loaded and unloaded, trucks can behave like horizontal transport, move freely on the terminal and load and unload certain loading units independently. Means of transport can visit several delivery positions. Accordingly, several pick-up positions can be visited after the unloading process. For larger means of transport such as train and ship, simultaneous loading and unloading is possible between pure unloading and pure loading.

3.4 Database

The backend generates data at simulation runtime, which is stored in an Access database to log the relevant values of the simulation run.

3.5 Experiment Data

The data used as a basis for the simulation correspond to those of a classic structure of a typical inland terminal. This consists of:

- six tracks with a length of 700m to accommodate block trains
- four gantry cranes
- two reach stackers
- a quay for barges

4 Results

We separate our results of the study into two main areas. We begin with a short introduction into the functionality, which sets out the workflow. Following this, the simulation results are presented, focusing primarily on the individual equipment units. Finally, the results are explained and thus a basis for discussion is given.

4.1 Functionality

As a result, it can be stated that the communication between frontend and backend works via XML interface. The terminal layout created statically with the visTABLE® software tool is automatically transferred to a dynamic simulation model and simulated with Enterprise Dynamics®. Furthermore, the output and visualization of the individual performance parameters of the modelled inland terminal was carried out.

4.2 Simulation Results

The results of the inland terminal simulation case are presented below.

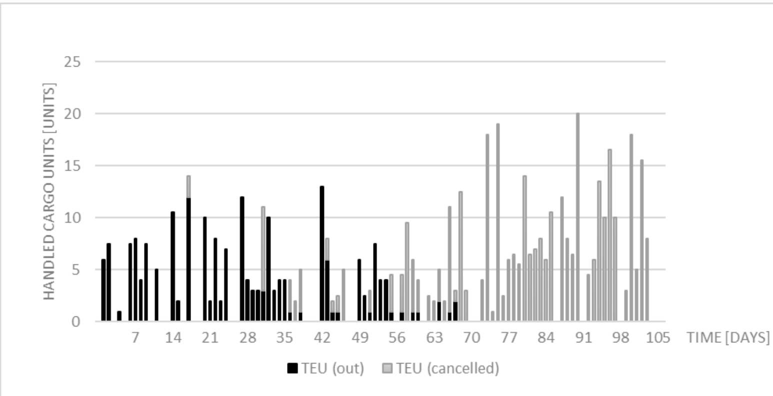


Figure 2: Handled cargo units

The number of loading units handled is of primary interest and indicates how many handling orders have been realized cumulatively per day. TEU (out) indicates how many loading units were regularly handled. TEU (cancelled) indicates which loading units could not be handled because at least one of the means of transport involved in the handling has already left the terminal again. The moving average levels out the fluctuation between the days and reflects the average of the seven preceding simulation days. An asymptotic approximation of this curve is an indication of a converging simulation run and thus an indication of a time range for which the simulation model can be regarded as "settled". Only then statements about the results of the simulation run are actually possible. The reason for this is that the terminal is completely empty at the start of the simulation and therefore no statement can be made about the performance for the first few days. As can be seen in Figure2, the curve has settled after a relatively short period of seven days and shows a surplus of regularly handled loading units at the beginning of the simulation. This situation changes from the beginning of the eighth week of the simulation. From this point on, the number of loading units that cannot be transshipped increases until no regular transshipments take place at all.

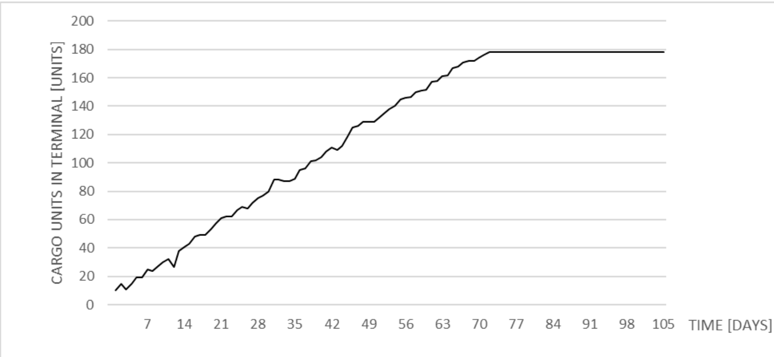


Figure 3: Cargo units in terminal

The size of loading units on the terminal indicates the maximum number of loading units on the terminal on a specific day. This information is independent of the type or size of the loading units. A 20-feet container is counted like a trailer. Figure3 shows an asymptotic approximation of the curve. This indicates that there is either maximum utilization of the equipment or overfilling of the yard. However, the curve shape may also indicate a lack of terminal performance due to the train schedules on file.

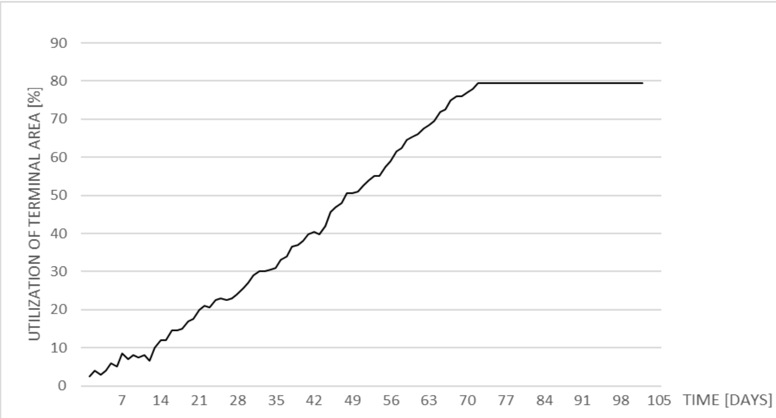


Figure 4: Utilization of terminal area

The utilization of the terminal spaces visualizes the occupancy of the terminal spaces with loading units. Since different loading units also occupy a different number of slots, all different loading units of the terminal are considered here.

If the curve approaches a high level, as shown in Figure4, this indicates a possible limit to the available capacity. This means that it may take a very long time to find a suitable slot for a loading unit. However, it can also be explained by a high number of restacking operations required by the equipment until it reaches the load unit to be transported.

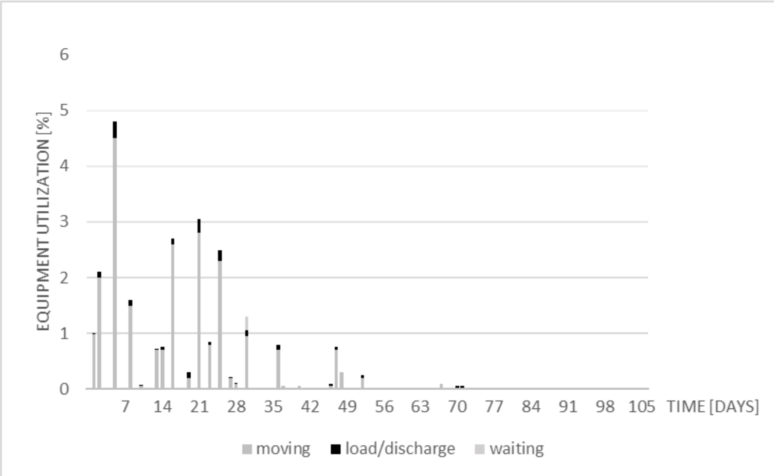


Figure 5: Crane utilization

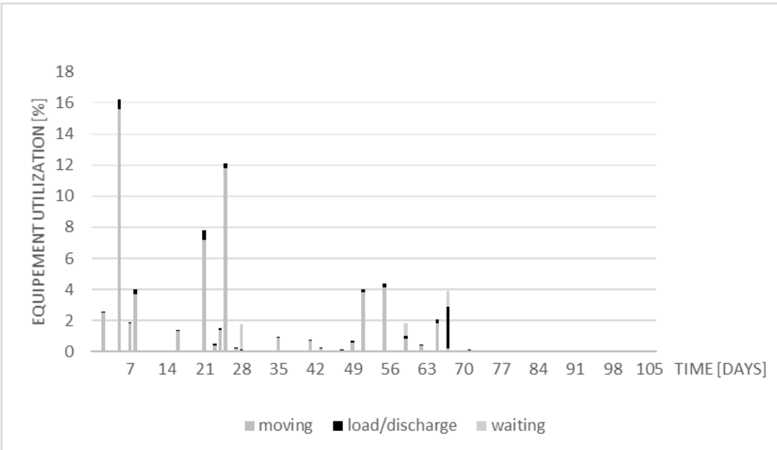


Figure 5: Mobile lifter utilization

For each equipment type it is visualized how this instance was used. The information is given as a percentage of the time capacity available per container. Waiting in this context means that the equipment had to wait for another equipment type to be able to realize a handling order. Driving and loading/unloading are the actually productive time shares during which either a loading unit is moved or the equipment moves to the position of a transfer position of a loading unit. Not shown are the time shares during which the equipment does not perform any activity. This is why the percentages on the left of the coordinate axis rarely range from 0 to 100%. Highly utilized equipment can represent a bottleneck, especially if the terminal areas themselves are only very lightly utilized. As can be seen from Figure5 and Figure6, the utilization of the equipment type crane and mobile lifter is very low. The maximum utilization rate for the crane is 4.8%, while the maximum utilization rate for the mobile lifter is 16.2%.

5 Discussion

The research question in this study aimed to determine how an efficient link between a static layout planning tool and a dynamic simulation tool can be designed. It could be shown that it is possible to implement an integrated solution that is able to communicate via an XML interface and fully automatically create a dynamic simulation modulation from a static layout, simulate it and output results on performance specific terminal parameters. Within the scope of a case study it could be proven that it is possible to design the inland terminal with the provided object library intuitively and efficiently in the graphical user interface of visTABLE® within an adequate time frame. Furthermore, it is possible to adapt the existing layout with little effort and to simulate it again for a later comparison.

Another new insight is that simulations of logistic nodes like inland terminals can be performed without any programming knowledge. This significantly expands the potential range of users of the integrated planning tool.

A limitation of our implementation is the creation of the path network. A possible explanation for this could be that the generation of multiple link points in the backend for each type of equipment used results in very long simulation times depending on the size of the model created. With regard to the parameter annual turnover of loading units, the initial model created on the basis of the classic parameterized inland terminal was restricted and adjusted to 2.000 loading units per year. These results are therefore rather disappointing that this was the only way to ensure a smooth simulation run. The results obtained for the performance of the terminal must therefore be interpreted with caution. Another limitation in this work concerns the question of strategy implementation. By defining strategies, it should be possible to influence the behavior and thus the performance of the terminal without changing the type and number of equipment or the spatial structure and dimension of the terminal. However, only the track usage strategy could be implemented so far, since due to the unexpected complexity a prioritization in the implementation of the strategies had to be done.

Effects for practitioners can be observed especially for operators of inland terminals. This applies in particular to small and medium-sized inland terminals that have no or limited access to expertise. For this mentioned group, the tool can be of great importance. The terminals are under pressure to handle loading units in ever shorter time windows while using as little equipment as possible. The economic circumstances result not only in monetary advantages, but also in ecological ones.

A successful balancing of these operational goals must be considered at an early stage of new construction or conversion, because the layout sets the course for later operation. With the integrated software tool, a layout planning tool and a simulation tool have been intelligently linked to reduce the planning and modeling effort for adaptations and new planning as far as possible.

6 Conclusion and Future Research

The ISI-Plan prototype is to be seen as a first debut work in this field. It aims to generate a benefit for future terminal planners and also operators in investment and planning questions for existing or planned terminals, as well as for expansions in the terminal area.

The major challenge of this work was that a direct coupling between layout planning and simulation with intuitive access for low-effort, responsive input by planners and operators of logistic handling points has not been yet been sufficiently investigated in the past and thus uncertainty existed with regard to the technical feasibility.

With the present work it could be shown on the basis of a case study that it is possible to develop an integrated software application that combines static layout planning and dynamic simulation of logistic nodes. The use of the application is not only intuitive and takes less time than previous solutions, but also does not require any programming. On top of that the synergetic use of known methods and competences of different disciplines as well as an added value for simulation-based planning could be achieved.

Further research could focus on making the simulation process more efficient. Furthermore, additional objects, processes and strategies could be included, as well as the possibility of adding further interfaces to enable the integration of a TOS system, for example. However, there is also the possibility of further developing the present concept in the direction of a digital twin of logistics nodes.

Financial Disclosure

This work was funded by the German Federal Ministry of Education and Research (BMBF) as part of the research project ”ISI-Plan - Integration von ereignis-diskreter Logistiksimulation und Layoutplanung für logistische Knoten”.

References

Angeloudis, P., Bell, M., 2011. A review of container terminal simulation models. Maritime Policy and Management, 38 (5), pp. 523–540.

Böse, J., 2020. Handbook of Terminal Planning. New York, Springer.

Brinkmann, B., 2005. Seehäfen - Planung und Entwurf. Berlin, Heidelberg. Springer.

Clausen, U., Kaffka, J., 2016. Development of priority rules for handlings in inland port container terminals with simulation. Journal of Simulation, 10(2), pp.95-102.

Dragovic, B., Tzannatos, E., Park, N., 2017. Simulation modelling in ports and container terminals: literature overview and analysis by research field, application area and tool. Flexible Services and Manufacturing Journal, 29 (1), pp. 4–34.

Eckert, C., Teitge, P., Steinhauer, D., 2013. Bausteinbasierte Simulation des Ladungsumschlags in trimodalen Containerterminals. In: W. Dangelmaier, C. Laroque and A. Klaas (Eds.): Simulation in Produktion und Logistik 2013, 09. - 11. October 2013. Paderborn, pp. 283–292.

Gharehgozli, A., Vernooij, F., Zaerpour, N., 2017. A simulation study of the performance of twin automated stacking cranes at a seaport container terminal. European Journal of Operational Research 261 (1), S. 108–128.

He, J., Huang, Y., Yan, W., 2015. Yard crane scheduling in a container terminal for the trade-off between efficiency and energy consumption. Advanced Engineering Informatics 29(1), pp. 59–75.

Kaffka, J., Clausen, U., Stein, S., 2014. Revealing gaps in the material flow of inland port container terminals alongside the Danube with simulation. 2014 Winter Simulation Conference - (WSC 2014). Savanah, GA, USA, pp. 1807–1818.

Kastner, M., submitted. Assessing Performance of Container Slot Allocation Heuristics Hamburg International Conference of Logistics (HICL) 2021.

Kemme, N., 2012. Effects of storage block layout and automated yard crane systems on the performance of seaport container terminals. OR Spectrum, 34, pp. 563–591.

Khaslavskaya, A., Roso, V., 2020. Dry ports: research outcomes, trends, and future implications, Maritime Economics & Logistics, International Association of Maritime Economists (IAME), vol. 22(2), pp. 265-292,

Nourmohammadzadeh, A., Voß, S., 2021. A robust multiobjective model for the integrated berth and quay crane scheduling problem at seaside container terminals. Annals of Mathematics and Artificial Intelligence.

Notteboom, T., Pallis, A., Rodrigue, J-P., 2021, Port Economics, Management and Policy, New York: Routledge

Schwientek, Anne; Lange, Ann-Kathrin; Holzner, Markus; Thomsen, Margit; Jahn, Carlos 2018, Integrating layout planning and simulation for logistic nodes. Hamburg International Conference of Logistics (HICL), 2018, 21-39.

Stahlbock, R., Voß, S., 2007. Operations research at container terminals: a literature update. OR Sprectrum 30(1), pp. 1-52.

Tan, C., Yan, W., Yue, J., 2021. Quay crane scheduling in automated container terminal for the trade-off between operation efficiency and energy consumption. Advanced Engineering Informatics 48, S. 101285.

Wurdig, T.J., Wacker, R., 2008. Generische Simulationslösung für Fördertechnik. In: M. Rabe (Ed.): Advances in Simulation for Production and Logistics Applications, pp. 12-20.

Yu, M., Liang, Z., Teng, Y., Zhang, Z., Cong, X., 2021. The inbound container space allocation in the automated container terminals. Expert Systems with Applications 179, S. 115014.