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Integrating Layout Planning and Simulation for Logistic Nodes

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When a new logistic node (e.g. a terminal) is planned or needs to be optimized, layout planning and simulation analysis are typically two separate tasks. While layout planning is an intuitive and visual but static approach, simulation is dynamic but more complex. Integrating both approaches would be highly beneficial. The idea of the integrated tool is to create first a static layout on a touchscreen planning table. After inserting relevant parameters and selecting preferred logistic strategies, the layout is converted directly into an executable simulation model. Based on the simulation, e.g. different layout or equipment variations can be tested.

Main challenges for a successful integration are the logistic processes and strategies on the terminal. Both are not included in the layout planning, but are essential for a valid and realistic simulation model. Therefore, relevant process and strategy variations as well as typical research questions are defined. The integrated approach is an innovative solution to optimize planned as well as existing terminals. Typically, conducting layout planning and simulation studies separately is a very time consuming task. Integrating both is more efficient, closer to reality and more cooperative by allowing to involve more stakeholders at an earlier stage.

Keywords: Simulation; Layout Planning; Inland Waterway Container Terminal; Intermodal Transport

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1 Introduction

In order to meet the high demands for faster handling in a shorter time window and with higher quality, it is necessary that logistical nodes in ports and the hinterland continuously review their operational and administrative processes and adapt them if necessary. This applies in particular to container terminals (Stahlbock and Voß, 2008) and intermodal terminals due to the high transshipment numbers and the increasing requirements. Therefore, when planning new and existing logistic nodes, it is important to use space and technical systems for handling, transport and storage as efficientl as possible. Simulation is becoming increasingly important for securing and optimizing solutions for planning processes in logistics in general (März and Weigert, 2011) and especially for container terminals. It is increasingly important to integrate the simulation in early planning phases and with little effort.

2 Problem Description

2.1 State of the art

Typically, terminal planning and terminal optimization by simulation studies are separate tasks. The terminal layout is planned statically using standard layouts, experiences, spreadsheets or other static tools. Afterwards, simulations studies can be conducted to evaluate and improve the terminal design. This would lead to adjustments in the terminal planning causing a high expenditure of time and high personnel costs. Furthermore, creating simulation models demands time and substantial soft are knowledge.

Common simulation tools for material flow and logistics like AnyLogic, AutoMod, CLASS, Demo3D, Enterprise Dynamics, Plant Simulation, Simul8, or Witness base on object libraries that provide the foundation to create a simulation model. These objects are defined by a number of parameters. The amount of parameters has to be the higher the more realistic the simulation is supposed to be. This implies that modelling large sites containing various parameter constellations is a highly complex and time-consuming task.

Additionally, control mechanisms and algorithms have to be defined to manage the simulation runs. All common tools provide predefined procedures. Practically, these procedures have to be adjusted by re-programming objects or programming new scripts. Target group of these tools are typically specifically trained users that intend to find answers to specific questions regarding an existing terminal layout.

In other areas of logistics, such as production planning (Toth et al., 2008) or conveyor system planning (Wurdig and Wacker, 2008), approaches have already been taken to integrate planning and simulation. However, these approaches cannot be directly transferred to the planning of logistical nodes due to a high number of organizational forms, many decision variables, static and dynamic side conditions and many sources of uncertainty, e.g. weather conditions or equipment failures. This is also the reason why many simulation models focus on defined area of seaport container terminals, e.g. automated storage blocks (i.a. Xin et al., 2014; Kemme, 2012; Canonaco et al., 2007), container gantry cranes (i.a. He et al., 2015; Guo and Huang, 2012; Dai et al., 2004; Liu et al., 2002) or horizontal transport (i.a. Garro et al. 2015; Tao and Qiu, 2015; Duinkerken et al., 2007). Other simulation models consider container terminals as a whole, but focus on medium to large seaport container terminals and do not offer the flexibility required for inland terminals or intermodal terminals.

2.2 Objectives

When layout planning and simulation studies for logistic nodes are conducted separately and decoupled, possible synergy effects (such as reducing the modelling time for a simulation model) are not realized. To approach these deficiencies, it would be beneficial to develop a soft are solution that allows creating static terminal layouts and to transfer this layout directly to an executable dynamic simulation model including the relevant terminal processes and strategies. These processes and strategies are of utmost importance for a successful integration as they represent the essential link between layout planning and simulation. Therefore, they have to be defined beforehand. By integrating intuitive and cooperative layout planning together with dynamic process mapping within one soft are solution, the strengths of both tools are combined while the weaknesses of both tools are eliminated at the same time.

In order to realize the integration of layout planning and simulation, two existing soft are tools are chosen. Thereby, the planning soft are visTABLE® by plavis and the simulation soft are Enterprise Dynamics® by INCONTROL represent the respective soft are. The integration can reduce the required time to plan a logistic node significantly as simulation models have to be modelled otherwise by experts in extensive work based on the designed layout.

Therefore, this innovation directly supports an efficien and rapid planning phase of logistic nodes to support an extension of transport infrastructure suitable to the market needs. The integration of layout planning and simulation studies is - in a first step - developed for inland waterway container terminals and terminals for intermodal transport. This means that whenever the term ’terminal’ is used in the following, these two terminal types are described. All other types of terminals such as e.g. seaport container terminals are not considered.

2.3 Methodology

2.3.1 Methodology to integrate both software tools

Baseline for such an integrated soft are tool are the *system specifications* that define all requirements for the tool. This comprises e.g. typical and relevant objects, processes and strategies to be implemented, but also relevant problems to be investigated with the tool and interesting output parameters of the tools for users later on.

Based on the system specifications, the *concept* is developed. A method needs to be described to define a systematic procedure how to implement the specifications. Basically, detailed use cases have to be described containing objects, processes, strategies, problems to be investigated and output parameters. This also includes e.g. describing core elements of a modular object kit and all selectable control strategies. Based on this method, detailed definitions of partial systems to be implemented later on are derived. Thereby, possible end users should be involved in this phase to ensure draftin user interfaces suitable for different types of users. Based on these results, a functional architecture of the planning environment can be derived.

If the concept is developed, the *implementation* phase begins. First, foundations have to be laid to allow for an integrated use of both soft are tools. There is a high number of interdependencies between results and restrictions from the layout planning and their transformation to an executable simulation model. These restrictions require adapting both soft are tools. The previously defined use cases have to be implemented together with the corresponding algorithms. Necessary

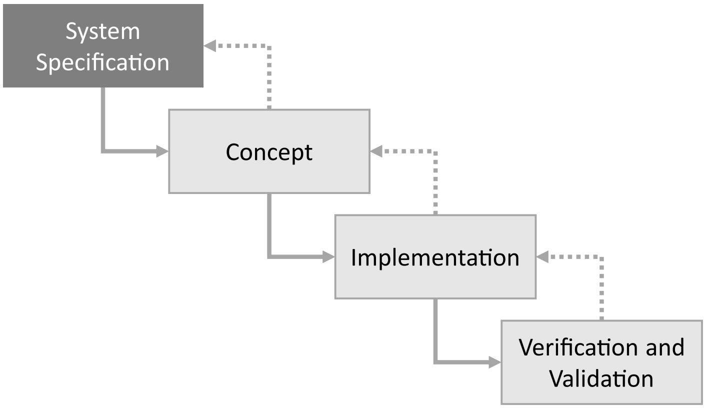

Figure 1: Methodology

interfaces and data structures that are defined in the system specifications need to be integrated in both soft are tools.

To verify the implemented soft are solution, extensive *tests* are conducted. First of all, the functional capability of the developed soft are tools is verified. This test bases on a test plan that contains all relevant test cases (e.g. choice of logistic strategies) based on systematic parameter variations. Afterwards, the functionality of the soft are is validated. Thereby, single specific test cases are considered. Afterwards, two exemplarily test applications show the comparability with real terminals.

Figure 1 displays the methodology. Thereby, the dotted arrows indicate that it might be reasonable to go back to the previous phase for some adjustments. The integrated soft are solution will be developed as a prototype within the German research project "ISI-Plan - Integration von ereignis-diskreter Logistiksimulation und Layoutplanung für logistische Knoten" which means "Integration of event-discrete logistics simulation and layout planning for logistics nodes". The project is funded by the German Federal Ministry of Education and Research (BMBF).

2.3.2 Methodology for the system specification

Based on this general methodology, the focus of this paper is on the first part, the system specification. Thereby, on the one hand scientific literature on terminal layout planning (e.g. Böse, 2011; Brinkmann, 2005) and terminal simulation (e.g. Dragovic et al., 2017; Angeloudis and Bell, 2011) is considered. On the other hand, the practical operational terminal processes are investigated in detail in order to validate the state of the art as well as to ensure the reference to recent terminal challenges.

First, a desk research is conducted to identify relevant publications in the field of container terminals. Thereby, not only inland waterway terminals and intermodal transport terminals are considered, but also seaport container terminals. This allows to include advanced technologies as well as storage and logistic strategies. Furthermore, websites of relevant logistic nodes as well as available studies and reports are analyzed to complete the findings with the state of technology. As there are sometimes significant differences between the functionalities and complexity of different logistic nodes, the findings are examined regarding their adaptability to inland waterway and intermodal transport terminals. This way, objects and strategies are considered as well that are less relevant at the moment but might become more important in the future.

Based on the desk research results, interview guidelines are developed that serve as a foundation for visits at two representative terminals. During these visits, detailed analyses of terminal operations, relevant parameters, planning issues and possible future topics are surveyed. Some interesting findings of both approaches (desk research and terminal visits) are presented in the following section.

3 Approach and functionalities

The goal of the research project ISI-Plan is the creation of a functional prototype consisting of the innovative integration of the planning table and the logistical process simulation. Therefore, that prototype will support the rapid and efficien planning and development of logistics hubs.

The tool will be tested in the project by the Institute of Maritime Logistics of the Hamburg University of Technology, the Fraunhofer Center for Maritime Logistics and Services CML, the Studiengesellschaft für den Kombinierten Verkehr e.V. (German Promotion Centre for Intermodal Transport), an inland waterway terminal and an intermodal terminal using corresponding example scenarios. The tool mainly uses a map of the area to be planned as input data. Based on this map, the user inserts suitable superstructures (such as portal cranes or reach stacker (RS)) at the desired location in the planning soft are. Standard parameters such as vehicle speeds or energy consumption can be adjusted as required. The layout is created using the planning table.

Furthermore, the user can choose between different strategies for the logistics processes in the terminal (e.g. assignment of RS to specific tasks, which water and landside container input for the terminal is to be simulated in a specific time interval and on how many trucks, trains and passenger ships these are distributed). Afterwards, the prepared layout can be transferred directly to the simulation soft are with all parameters. The performance of the planned terminal layout can be tested using the generated simulation model.

In summary, the tool is characterized by the following functionalities:

1. Intuitive layout planning via ”drag and drop” for logistics nodes (on a planning table)
2. Automatic creation of a simulation model based on the planned layout
3. Selection of different logistics strategies and parameters as well as input quantities of the logistics node
4. Execution of simulation tests to measure the performance of a layout alternative

To realize the prototype, both soft are tools visTABLE and Enterprise Dynamics will be linked bidirectional by special interfaces. One major issue is the implementation of logistics strategies and process flows in these logistics hubs.

Figure 3 displays the basic concept of that prototype with its characteristic functionalities. Using the ISI-Plan prototype, the layout planning is done with visTABLE by using the planning table. The user can create any terminal layout by using predefined logistics objects from the visTABLE library and drag-and-drop these to the modelling layout. Each object has a set of default parameters and a visual representation that can be modified by the user. Additionally to the modelling of the layout in visTABLE the user also defines the logistics strategies and processes to be used later on in the simulation model and defines the target values to measure the performance of the layout.

When the modelling process is finished in visTABLE all data is transferred to Enterprise Dynamics. The simulation tool then automatically creates the simulation model with all applied objects, parameters and additional settings and automatically runs the defined simulation experiments. The defined target values are measured during each simulation run and are stored in a database. After the simulation experiments the result data is returned to visTABLE where the user gets these results presented in the form of e.g. diagrams and tables.

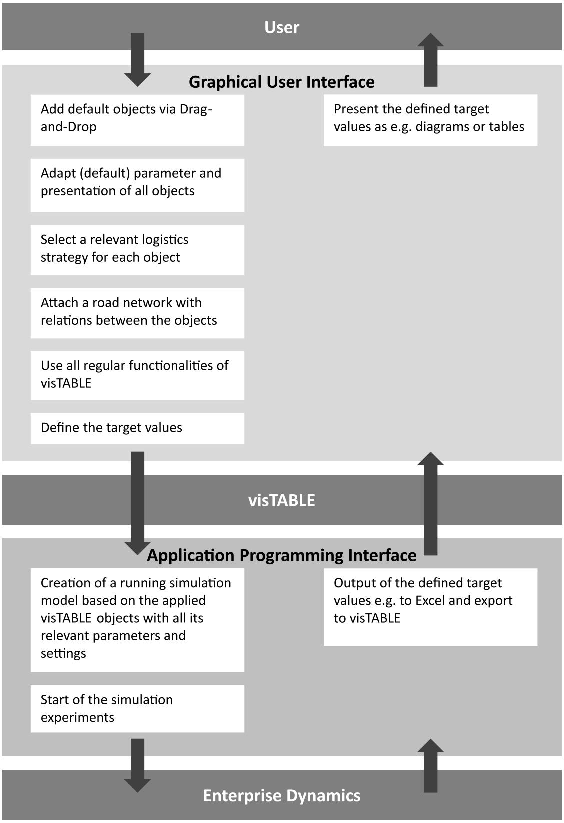

Figure 2: Overview of the functionalities of the prototype

4 System specification

As mentioned beforehand, the system specification defines which objects, processes and strategies, relevant problems and output parameters should be included in the new soft are tool. All of these issues are presented in the following section.

4.1 Objects

In the following, relevant objects and corresponding parameters for the integrated soft are are described. The objects are grouped in five categories: vertical transport, horizontal transport, external vehicles and means of transport, loading units (LU), terminal areas.

The category *vertical transport* comprises terminal equipment whose main function is to lift a LU from a horizontal transport vehicle or a storage area and to place the LU on another horizontal transport vehicle or a storage area. Although, technically, a certain horizontal transport takes place, this is neglected in this common classification. The pure vertical transport on terminals is carried out by cranes (e.g. gantry cranes, mobile harbor cranes).

Vehicles are assigned to the category *horizontal transport* if their main function is to transport LUs from one vertical transport equipment or storage area to another vertical transport equipment or storage area. However, some equipment types, such as RS, are capable of both vertical and horizontal transport and are used accordingly, e.g. for unloading a LU from a truck, transporting the LU across the terminal area to a storage area and stacking the LU on other LUs in this storage area. Within this classification, these hybrid forms are assigned to horizontal transport. A distinction is made within this group into active and passive vehicles. Active load carriers can independently receive LU, while passive vehicles must be loaded by another equipment type. Examples for vehicles in this category are empty container handlers, reach stacker, tractor-trailer-units and shunting engines.

While they are not classified as terminal equipment due to their deviating ownership, *external vehicles and means of transport* are nevertheless very important objects for the handling of goods at terminals. They are used to carry out the incoming and outgoing volumes of LU to terminals as logistical transshipment nodes. Examples of external vehicles are trucks, trains and barges.

Loading units are transport containers through which various goods can be transported and handled in a standardized manner. The most important example of this are containers, which in turn can be divided into various subclasses such as standard, empty, reefer, open top, tank and flat racks. Other LUs can be swap bodies and trailers.

Within the category *terminal areas*, almost all terminals have a paved road area in common for the arrival and departure of trucks. Furthermore, a terminal has shunting and loading tracks. The track length for a so-called block train, i.e. a train with the maximum permissible length, measures 750 m in Germany. For tracks with half lengths, the block train must be divided and shunted. The loading and unloading tracks are usually straddled by gantry cranes handling the LUs between road and rail. In larger terminals, RS are often used to support the gantry cranes. The short-term storage area for LUs is located under the crane runway. Additional storage areas can be realized in the vicinity of the crane runway and must be operated by a RS. Administration buildings, entrance areas and fences are also part of the terminal area category.

4.2 Processes

Terminals in general serve as transshipment points between different modes of transport. Inland waterway container terminals and intermodal transport terminals are typically part of the pre- respectively post-carriage processes of maritime transports. This implies that, typically, containers and other LUs arrive at these terminals by train or barge from a seaport terminal, and they are picked up by trucks for further distribution (or vice versa). Intermodal transport terminals are also integrated in other transport chains such as e.g. CEP (courier, express and parcel) services.

Usually, all main cargo handling processes on the terminal begin when an external vehicle arrives at the terminal with a LU and end in the short-term storage area or vice versa. However, there is also the possibility that a LU is directly transferred from one external vehicle (e.g. train) to another (e.g. truck) without stopping in the storage area.

Figure 3 and Figure 4 show exemplarily the processes ”pick-up by truck” and ”delivery by train”. The processes were mapped on terminals of project partners and afterwards generalized based on industry knowledge and scientific literature. They are displayed in swim lane diagrams. The darker boxes on the left show the respective actor, the medium grey boxes show the single process steps of the main process. The light grey boxes indicate the transition to other main processes. The arrows show the order of the single process steps.

Pick-up by truck - as displayed in Figure 3 - is quite similar in all terminals. The empty truck arrives, the driver registers either at a counter or on a self-service terminal, drives to a specified transfer position, is loaded with the LU by crane or RS, and afterwards leaves the terminal. In some cases, the loaded LU is checked whether it is the right one (if not, he LU has to be changed). Therefore, even if different equipment is used, the processes stay relatively constant.

In contrast, *delivery by train* varies widely depending on the equipment that is used is the train area (see Figure 4). When a train arrives, it registers, and the offi e generates an order list for the handling equipment based on the train load list. If a RS is used for unloading the train, the driver unloads an accessible LU, the checker checks the LU for damages and whether it is the right one, and then the RS transports it to the respective storage position and places it in the storage area (or on a truck that picks up the specific LU). If there are any restrictions regarding the accessibility of the train, a shunting engine is used to shunt the rail cars. If a crane if used in the train area, the checker first checks all LUs on the train before the crane starts unloading. If the LU is a trailer, the crane places it directly in the crane runway where it is picked up either by an internal tractor to be pulled to a trailer storage area or directly picked up by an external truck. If the LU is a container or a swap body, it is either placed in the storage area or directly on a waiting external truck. When all LUs are unloaded from the train, the order list is returned to the offi e together with remarks from the checker.

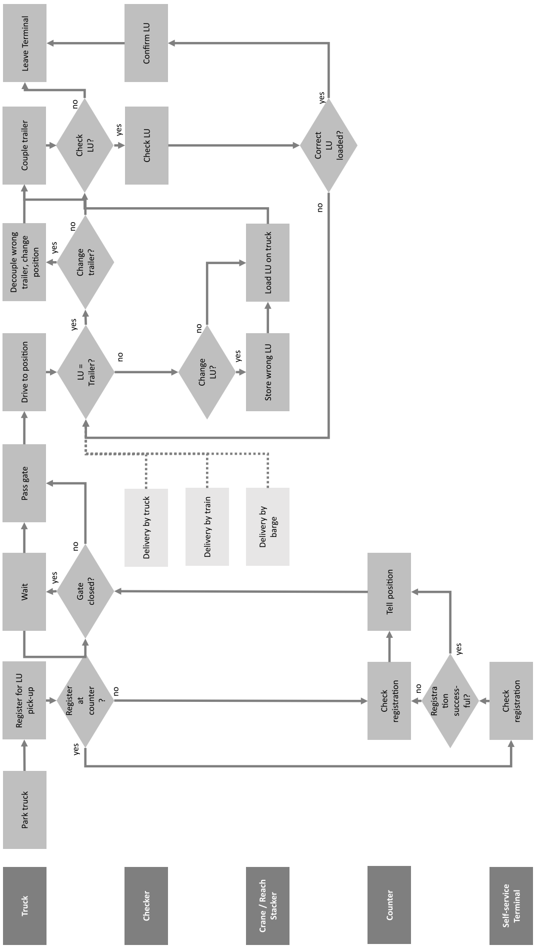

Figure 3: Process ”Pick-up by truck”

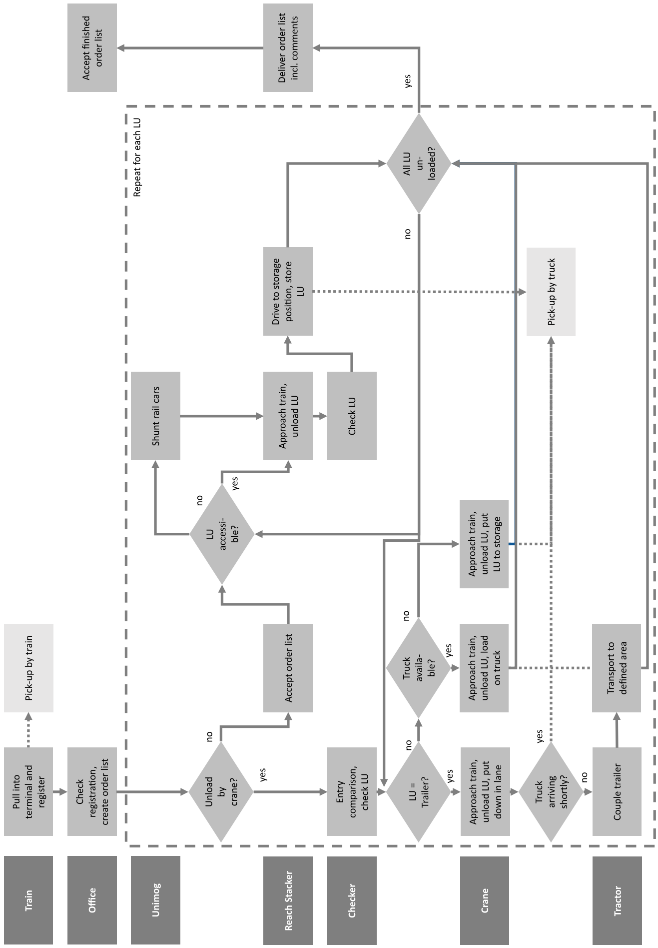

Figure 4: Process "Delivery by train"

These two process examples illustrate the challenges for a soft are tool that automatically generates a simulation model based on a static layout. The objects have to be connected to the respective process variations. However, implementing logistics strategies is another challenging topic.

4.3 Strategies

Various strategic and operational decision problems arise during the planning and operation of terminals. Strategic decision problems are of a longer-term nature and only arise infrequently, while operational decision problems occur in daily terminal operations. Figure 5 assigns strategic and operational decision problems to the respective terminal areas.

The strategic decision problems ”layout” as well as ”type and number of equipment” are essential research subjects of the soft are tool to be developed. The operational decision problems relate to the question of how a certain process step is carried out, e.g. how a decision is made, where exactly a LU is stored or to which transfer position a truck is steered to or which task a gantry crane performs next. The strategies can be used to make these decisions and are therefore solutions to the decision-making problems. For the tool to be developed, this means that for the relevant part of the decision problems, different variants of strategies that are typically used in terminals must be implemented. In the following, some exemplarily strategies are described.

Prioritization or assignment of tasks is about which gantry crane / RS / tractor performs which task next. Thereby, a task is to change the location of a LU (i.e. load, store, etc. the LU from the train/truck/barge). Possible strategies include: First-come-first-served, minimize distances, minimize travel time to job start location, select order with the longest waiting time, prioritization of task types (e.g. train before truck), scoring strategies, or restacking / presorting at low utilization (cf. Kaff a et al., 2014; Clausen and Kaff a, 2016; Eckert et al., 2013).

The *assignment of barges* to berths is only a relevant decision problem if there is more than one berth. One possible strategy, especially with a fixed weekly timetable, is that the assignment is always the same which means that a weekly arriving barge always gets the same berth.

The *transfer position* for an external truck refers to where on the terminal the truck hands over or receives the LU. The strategy depends among other things

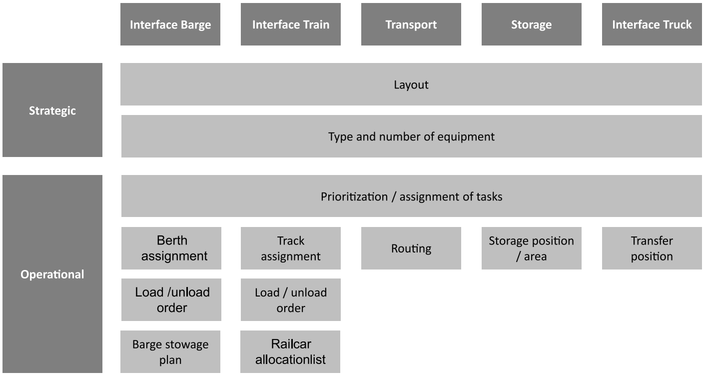

Figure 5: Decision problems on inland waterway and intermodal terminals

on the terminal size. For a small terminal, this can be one defined place. The following strategies are possible for larger terminals: minimize distance to planned storage position, minimize distance to current crane position, minimize distance to planned or current position on the train (during train loading or unloading), or minimize distance to an empty space in the storage area (especially at high storage area utilization).

These examples illustrate on the one hand that there are several similarities between seaport container terminals, inland waterway container terminals and intermodal terminals. On the other hand, the relevant strategies for inland waterway container terminals and intermodal terminals are rather simple, some seaport-related strategies are not relevant (e.g. berth assignment as most considered terminals have no or one berth), and there are other challenges as e.g. gantry cranes are used for several tasks in parallel (cf. e.g. Jaehn, 2013).

4.4 Relevant questions

The questions that the prototype should be able to analyze are part of the decision problems mentioned in section 4.3. The most important questions relate to the storage area as well as the barge and train handling. They were identified in discussions with different terminal experts.

Storage area-related questions are: How many storage lanes are required? How large (length, width, height) should the storage area be? Which equipment should be used and how much equipment is required by which equipment category? Which storage area organization respectively position assignment is best? Up to which storage utilization is terminal operation still productive? How do the dwell times of LUs affect the productivity of the terminal? Which order should the equipment process next?

Barge- respectively train-related questions are: What influence does the logic have on the occupancy of the tracks/ berths? Which equipment should be used and how much equipment is required by which equipment category?

4.5 Output parameters

Eventually, the soft are tool has to provide output parameters that are important to decision makers to choose the best alternative for the specific terminal. Depending on the terminal and the question that is analyzed, different output parameters are important. In general, the following output parameter have a high priority to terminal decision makers: Number of LUs handled (per year/month/-day/hour), equipment utilization, utilization of space, number of delayed train departures, distances travelled by vehicles (per LU), and moves/h per equipment. Output parameters with a medium priority are e.g. cycle time of (sub-)processes, duration of the train's stay at the terminal, fuel consumption, power usage, personnel expenses, equipment wear, and noise emissions.

5 Conclusion and Future Research

This innovative soft are tool directly supports efficien and fast planning of logistic nodes, which are necessary for a demand-oriented expansion of the transport infrastructure. In Germany alone there are more than 300 logistic nodes that can benefit directly from the integrated planning and simulation tool.

Further research could extend the scope of the prototype to other logistic nodes and even seaport container terminals. It could also include additional objects, processes and strategies. Also new technologies could be tested more easily as well as time and cost efficientl .

Financial disclosure

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