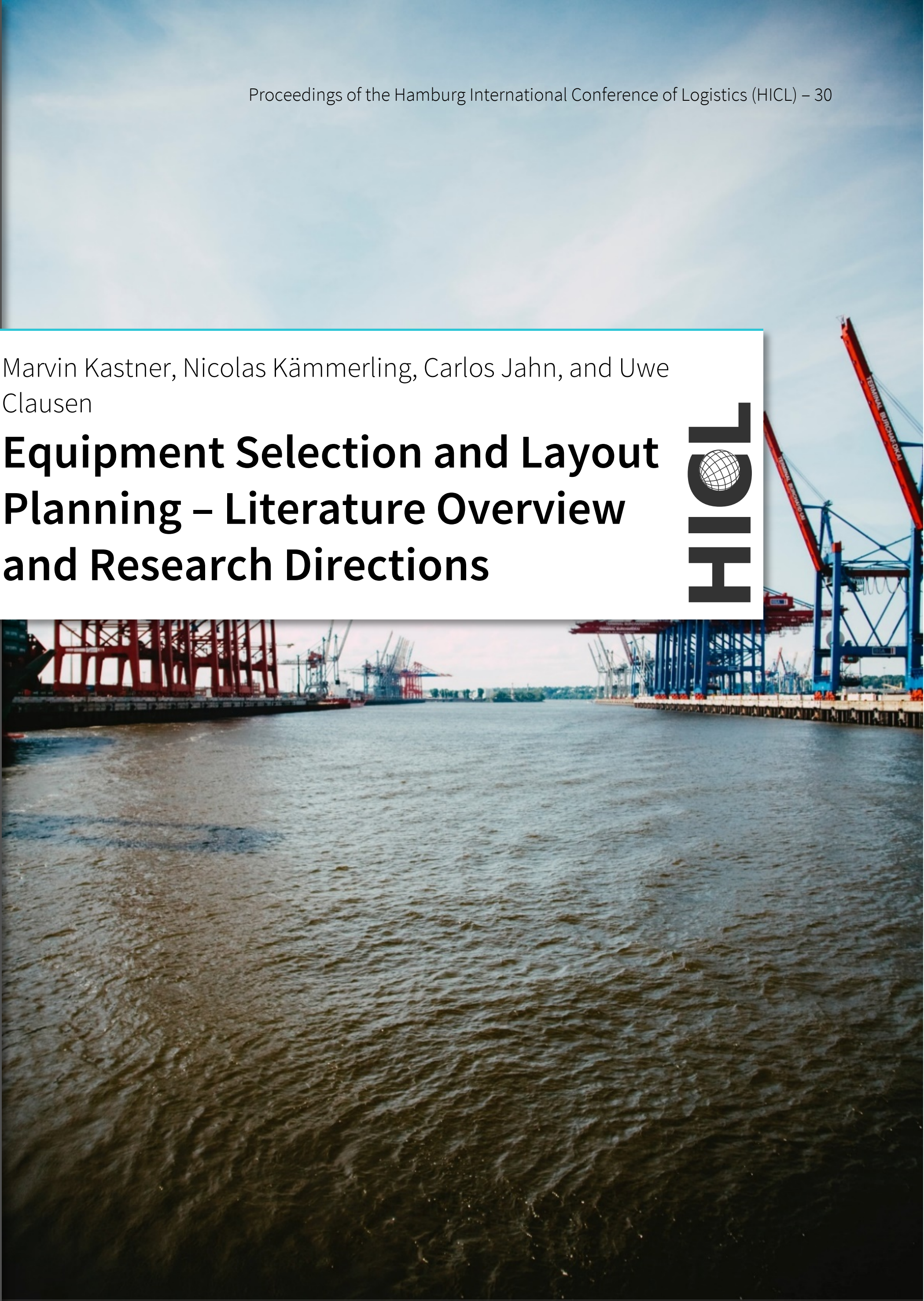
Proceedings of the Hamburg International Conference of Logistics (HICL) – 30



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Equipment Selection and Layout Planning – Literature Overview and Research Directions

Published in: Data science in maritime and city logistics
Carlos Jahn, Wolfgang Kersten and Christian M. Ringle (Eds.)
ISBN: 978-3-753123-47-9 , September 2020, epubli

Equipment Selection and Layout Planning – Literature Overview and Research Directions

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Purpose: When container terminals are planned or converted, among others the most suitable container handling system needs to be selected and the appropriate terminal layout needs to be designed. These two planning activities are mutually dependent and affect the costs and future operational performance. This leads to the question of how to arrive at a (near-)optimal solution for given criteria.
Methodology: A mapping review is conducted to investigate how the container handling system is selected and how the terminal layout is designed. Literature is examined regarding the employed methodology, the performance indicator(s) to optimize, and the way terminal layout and equipment selection have been jointly considered.
Findings: Various methods have been used to assess a suitable container handling system and the appropriate layout. Commonly, mathematical optimization is used to arrive at a suggestion and simulation is the tool to evaluate proposed decisions. Aspects such as handling costs, travel distances, or ecological factors are sought to be optimized.
Originality: Several literature reviews in the past years investigated approaches to the plethora of scheduling problems at container terminals. Here, the two strategic planning activities equipment selection and layout planning are presented in detail. This publication focuses on how the dependency of the two activities has been handled in literature.

First received: 06. Mar 2020 Revised: 25. Jun 2020 Accepted: 12. Aug 2020

1 Introduction

Over the last twenty years, global containerized trade has tripled to approximately 150 million 20-foot equivalent units (TEU) with trade relationships growing and ceasing between countries (UNCTAD, 2020). These unpreceded trade volumes supposedly challenge container terminals, especially since nowadays ultra large container vessels reach up to approximately 24,000 TEU (MDS Transmodal, 2018; Marine Insight News Network, 2020). According to UNCTAD, this leads to fewer but intense workload peaks at container terminals compared to the previous comparably steady stream of smaller ocean-going vessels. Furthermore, carriers plan to deepen their involvement in hinterland transportation (UNCTAD, 2020), which ultimately shifts power from the container terminal operators to the carriers. Therefore, container terminal operators need to improve their position in the maritime supply chain.

One opportunity to enhance the competitiveness of a container terminal is to automate container handling processes. Wang, Mileski and Zeng (2019) stress that the market position is elementary when choosing the automation strategy fitting to the individual requirements. The authors classify container terminals either as international gates (import and export) or as transshipment terminals. If markets are relatively stable and the throughput is certain, automation enables the operator to improve the service. At international gates, operators use automation to obtain low prices whereas at transshipment terminals automation helps reducing berthing times of the vessels and fulfilling the promised schedules reliably. Some container terminals continue to use manned equipment because of the greater flexibility. Altogether, there is no one-fits-all strategy - depending on the role the container terminal plays in the supply chain, individual solutions need to be found. At the same time, a general trend to automation persists.

The construction of an automated container terminal requires careful planning. Kaptein, et al. (2019) emphasize that later structural changes are very expensive. Inter alia, during construction the terminal planners place the rails of the yard cranes determining the later yard block layout. They also decide the thickness of the pavement determining the feasible pathways of heavy equipment. Only in the latest stage of construction, often the future container terminal operator is chosen and included (Kaptein, et al., 2019). This means that the terminal planners determine the role of the future container terminal in the maritime supply chain. Considering the analysis of Wang, Mileski and Zeng (2019), this approach is rather counterintuitive since the operator might want to pursue a different business strategy. Therefore, it is beneficial to leave the selection of the equipment and the layout to the later container terminal operator (cf. Böse, 2011).

The container handling processes from the time the container enters the container terminal by vessel, barge, train, or truck until it leaves the facility again display a great complexity. Hence, the container terminal is often divided into suitable subsystems (Voß, Stahlbock and Steenken, 2004; Stahlbock and Voß, 2007; Gharehgozli, Roy and Koster, 2016). For the presented publication, such a division into spatial subsystems is shown in Figure 1. The separation is based on Böse (2011), only that the horizontal transport from the quay cranes to the yard is considered as the separate subsystem "*(Waterside) Traffic Area*" following the perspective of Ranau (2011). Previously, Kemme (2013, p. 41) has suggested a similar spatial segmentation of a container terminal under a different naming. This publication uses the names prevailing in the literature cited herein. In this figure, the segmentation of the different terminal areas of concern are defined.

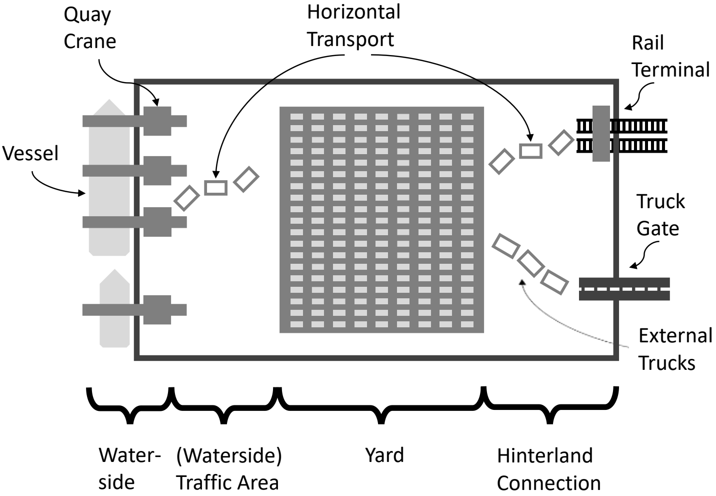

Figure 1: A schematic layout of a container terminal

At a container terminal, usually two container flows prevail: Import/export and/or transshipment. For brevity, in the following only the import flow is sketched out. At the waterside, major container terminals use quay cranes to load and unload the vessels. From there, the containers are transported to the yard. By means of stacking equipment, the container is stored there until sent to the hinterland (alternatively: transshipped). Depending on the mode of transportation, either internal horizontal equipment delivers the containers to the rail terminal or the external truck picks up the container from the stacking equipment in the yard. This schema lacks specific container handling equipment and layout. These are examined in the following two subsections.

1.1 Equipment Selection

First, a quay crane model needs to be chosen that satisfies the requirements of the container terminal. This includes the required size to serve the vessels as well as the moves per hour. After the quay crane has picked up a container, different types of equipment can horizontally transport the box to the yard. The main differentiation lies between self-lifting and non-lifting vehicles: Automated Guided Vehicles (AGVs) or yard trucks are considered non-lifting vehicles whereas Automated Lifting Vehicles (ALVs) and Straddle Carrier (SC) are described as self-lifting vehicles (Carlo, Vis and Roodbergen, 2014a). The authors indicate three common decision problems in transport operations: (a) choose the vehicle type, (b) determine the fleet size, and (c) determine according to which algorithms and rules each vehicle will operate. The first two decision problems are considered to be in the scope of this paper following the 3-Level-Model of Böse (2011). In the yard, commonly found stacking equipment are Rubber-Tired Gantry (RTG) cranes, SCs, and automated Rail Mounted Gantry (RMG) cranes (Wiese, Kliewer and Suhl, 2009). RMGs and RTGs can be summarized as yard cranes. The set of used equipment types is summarized as the container handling system of a container terminal (cf. Böse, 2011).

The wide range of possible container handling system raises the question how to arrive at the best solution for a given container terminal. Brinkmann (2011) presents a rule of thumb for which desired yard capacity (expressed in TEU per hectare) which container handling system including the fleet size is suitable. Johnson (2010) argues that with technological advances, one needs to be careful not to copy outdated solutions from other container terminals but instead to stay innovative.

1.2 Layout Planning

In this publication, layout planning covers the planning of berths, designing the traffic area, the yard including the orientation and dimensions of yard blocks, and the facilities needed for the hinterland connection. The scope is reduced to the aspects of the layout which directly affect the simplified flow of containers through the terminal. Other necessary aspects of planning such as positioning maintenance buildings, staff buildings, or planning the supply & disposal networks are neglected.

Kastner, Lange and Jahn (2020) examine a range of expansion projects at container terminals. In industry, simulation has been most often reported as the quantitative tool to examine a suggested expansion plan. A structured comparison of different layout options considering the same equipment have not been presented. At the same time, linking layout planning and an automated evaluation has been worked on in different projects. Gajjar and Ward (2016) propose a Microsoft-Visio-based tool that derives terminal characteristics such as throughput capacity from a 2d layout. In the project TRAPIST, a terminal planning board is designed that can enter a simulation mode to answer questions regarding operational, equipment, and layout problems (Yang, et al., 2008). Sun, et al. (2013) propose an integrated simulation framework that couples a geographic information system and a multi-agent system. In all instances, the terminal layout is created first and either static formula or simulation models inform the planner about estimated operational characteristics.

1.3 Related Work

Regarding seaport container terminals, frequently literature reviews are compiled (Voß, Stahlbock and Steenken, 2004; Stahlbock and Voß, 2007; Gharehgozli, Roy and Koster, 2016), some with a specific focus, such as scheduling problems in seaside operations (Bierwirth and Meisel, 2010; 2015; Carlo, Vis and Roodbergen, 2015), operations in the yard (Carlo, Vis and Roodbergen, 2014a), or horizontal transport operations (Carlo, Vis and Roodbergen, 2014b). The time horizon of the various problems differ, as well as the area of focus on the container terminal. Long-term planning problems such as layout design have been previously summarized (see e.g. Gharehgozli, Roy and Koster, 2016). The wide scope of such literature reviews has prohibited deeper insights into the matter.

The research question at hand is how to arrive at a (near-)optimal plan covering the container handling system including the fleet sizes and the corresponding layout. Three approaches are theoretically feasible: (1) Given a fixed layout, the container handling system is chosen, (2) Given a fixed container handling system, the layout is chosen, or (3) both container handling system and layout are jointly arrived on (cf. Welgama and Gibson, 1996). Wiese, Suhl and Kliewer (2011) argue that the required terminal capacity both influences the layout and the equipment selection but in practice a prevailing sequence of planning activities exists: The equipment is chosen according to the required capacity for the respective area and the available space. In the aftermath, the layout is planned accordingly - considering equipment-dependent details such as driving lanes and maneuvering areas. The authors' narrative compilation of publications focus on terminal layout planning neglecting the variety of factors that influence the equipment selection process.

Gharehgozli, Zaerpour and Koster (2019) review different container terminal layouts and point out different possible future developments, such as expanding by adding or reclaiming land, collaborating with inland terminals, constructing offshore container terminals, or moving empty containers to external depots. In addition, several innovative solutions such as container racks or overhead grid rail systems are presented. According to their three-step framework, simulation and queueing models are used to estimate throughput performance during the first two steps *layout analysis* and *design optimization*, whereas mathematical optimization is said to be more suitable for scheduling problems within the last step.

2 Literature Review

The research question at hand is how equipment selection and layout planning depend on each other. This targets at finding existing approaches and shortcomings of the research undertaken so far. A suitable review type for this is a mapping review (see Grant and Booth, 2009). Scopus and Web of Science served as databases for the research with each estimated 75 million records (Clarivative Analytics, 2020; Elsevier, 2020). The search is restricted to scientific publications in English. The year 2020 is excluded for repeatability. The search terms are selected in accordance with the wording in (Böse, 2011): For each publication the term "container terminal" is obligatory. Then the publication are filtered to either contain the term "equipment choice", "equipment selection", "container handling system" or both the terms "planning" and "layout". This resulted in a total amount of 129 results. Here, first the abstract and if deemed suitable the full texts have been analyzed.

First, only seaport container terminals are considered. This is deemed necessary for a fair comparison of the publications regarding the different functional areas on the terminal, e.g. at inland container terminals no quay cranes are used. Second, the main topic of the publication needs to cover the choice of an equipment type and/or the terminal layout. This is only a subset of what is typically referred to as terminal superstructure planning (Böse, 2011). Hence, only long-term decisions are considered which require some structural change at the container terminal. Third, only a publication with a comparison of at least two different presented alternatives are considered. This shifts the focus to publications which explain why under given circumstances one solution is preferred. This selection process reduced the number of publications to 28 which are presented in Table.

2.1 Considered Terminal Areas

The literature retrieved by the previously presented search process covers the container terminal including all terminal areas as they have been depicted in Table 1. To analyze which terminal areas are of specific concern, in Table for each publication the covered terminal areas are marked. Three shades of gray convey the degree these areas (or more precise: the container handling operations occurring there) have been considered. The lightest shade of gray expresses that either a single operational scenario is considered or the area is completely excluded from consideration. The intermediate gray reflects that alternative operational scenarios are considered. This could be e.g. an analysis to see how a container handling system or a layout would perform for specific traffic schedules or during peak utilization. The strongest shade of gray indicates that for that specific terminal area alternative container handling systems or layout options are compared. This can be either a manually constructed solution as it is common for simulation models or a solution created by an algorithm, e.g. from the domain of mathematical optimization. Furthermore, for each publication the dominating method(s) are considered. These are presented and explained in Table. A publication is only assigned a specific method, if the work related to the method including the results is presented to the reader in a comprehensible way. This includes that the reader is informed about the scope of the model (including its limitations) and that the results are presented in a way that makes it clear how the results from the model have influenced the later recommendation or decision.

Table 1: Identified Methods for Equipment Selection and Layout Planning

Acronym	Method	Description
CAP	Capacity calculation	Based on yard size and yard equipment, the annual container handling capacity is estimated
CON	Conceptual evaluation	Pro and contra arguments are weighed up and justify the preferred option If MUL present: This applies to at least one criterion
FIN	Financial cost model	A calculation that at least covers initial investment and costs during operation
MO	Mathematical optimization	A selection of a (near-)optimal solution from a given set of feasible solution.
MUL	Multi criteria optimization	Several criteria are summarized in one common score to determine the best solution
QT	Queueing Theory	As part of probability theory, it is used to predict waiting times for systems
SIM	Simulation	The terminal processes in focus are modelled, e.g. with discrete-event or agent-based simulation

Table 2: Publications presented by covered terminal area and methods

	Terminal Area				
Publication	Quay Side	Traffic Area	Yard	Hinter-land Con.	Methods
Asef-Vaziri, Khoshnevis and Rahimi (2008)	░	▒	█	░	SIM
Basallo-Triana, et al. (2019)	░	░	█	░	MO
Bardi and Ingram (2010)	░	█	░	░	CON
Chu and Huang (2005)	█	█	█	░	CAP
Crawford-Condie and Peet (2017)	░	█	█	░	MUL CON
Edmond and Maggs (1978)	█	░	█	░	QT
Golbabaie, Seyedalizadeh Ganji and Arabshahi (2012)	░	█	█	░	MUL CON
Gosasang, Yip and Chandraprakaikul (2018)	░	░	█	░	FIN
Huang and Chu (2004)	░	░	█	░	FIN
Hubler (2010)	░	▒	█	░	MUL SIM FIN CON
Kemme (2013)	▒	░	█	░	SIM

	Terminal Area				
Publication	Quay Side	Traffic Area	Yard	Hinter-land Con.	Methods
Kim and Kim (1998)	□	□	■	□	MO
Kim, Park and Jin (2008)	□	□	■	□	MO
Ludema (2002)	□	■	□	□	FIN
Meisel and Bierwirth (2011)	■	□	□	□	MO
Pachakis, Libardo and Menegazzo (2017) (offshore)	□	■	■	■	CON SIM
Pachakis, Libardo and Menegazzo (2017) (onshore)	□	■	■	□	CON SIM
Sauri, et al. (2014)	□	■	□	□	SIM FIN
Vis and Harika (2004)	▨	■	▨	□	SIM
Vis (2006)	▨	□	■	▨	SIM
Veshosky and Mazzuchelli (1984)	□	■	■	□	CON FIN
Wiese (2009)	□	□	■	□	MO

	Terminal Area				
Publication	Quay Side	Traffic Area	Yard	Hinter-land Con.	Methods
Wiese, Kliewer and Suhl (2008)	□	■	■	■	MO SIM
Wiese, Suhl and Kliewer (2009)	□	■	■	■	MO SIM
Wiese, Suhl and Kliewer (2010)	□	□	■	□	MO
Wiese, Suhl and Kliewer (2011)	□	□	■	□	MO
Yavary, et al. (2010)	■	□	□	□	SIM
Yan, Fang and Lu (2013)	■	□	□	□	MUL FIN
Yuan (2011)	□	□	■	□	MO

From the total 28 publications in Table 2, 16 cover equipment and/or layout alternatives in the yard, 11 in the traffic area, 4 at the quay side, and three at the hinterland connection. Of those, one publication describes an offshore container terminal which is connected to an onshore container terminal via barges. Hence, for the offshore container terminal the hinterland connection is that barge system. Only 7 publications considered different operational scenarios.

The most commonly used methods are mathematical optimization and simulation with each 10 occurrences. In 7 cases, a financial model is formulated. When considering several criteria, in 6 publications by means of argumentation one option is chosen and 4 publications created an aggregated score by weighting different aspects, e.g. the environmental impact, the duration of construction, or the safety for workers. One publication covered how the annual capacity can be estimated a priori and one uses queueing theory.

2.2 Estimating the Impact of Decision on Operations

When container terminal operators need to decide between different types of equipment and corresponding layouts, they need to estimate the impact of such choices: Will they be able to cope with the traffic demands both on average and during peak workload? Is there an alternative that could save them time and that would smoothen the operation, e.g. by shorter transportation distances? In Table, two different quantitative tools clearly dominate, i.e. mathematical optimization and simulation. In addition, both the waterside traffic area and the yard are covered best. To get an insightful comparison, in the following the literature using mathematical optimization and simulation are presented separately. For each group, the literature is restricted to publications covering the traffic area and the yard.

2.2.1 Mathematical Optimization

Mathematical optimization is the selection of the optimal solution from a set of given alternatives. It is therefore advantageous to use a mathematical optimization technique in the strategic planning phase of logistic systems such as container terminals. However, the problem has to be simplified in order to express the container handling processes into mathematical formulas.

As visualized in Table, it can be observed that mathematical optimization techniques are mostly considered for the layout planning of container terminals. The book chapter of Meisel and Bierwirth (2011) is a pure exception as the equipment section is focused. The authors propose an optimization model for crane capacity dimensioning at the quay of a maritime container terminal. Beside the number of quay cranes, the model decides on the berthing position of the container vessels. A greedy heuristic is used to solve the formulated formulation.

Besides the equipment selection, there is a series of publications about mathematical optimization regarding the layout configurations of a container terminal. This starts with the analytical method of Kim and Kim (1998) which simultaneously determines the amount of space and the amount of yard cranes.

Kim, Park and Jin (2008) present formulas in order to determine the expected number of relocations caused by picking a container which is stored under other containers as well as the expected traveling distances of yard trucks. Given this measurement, the authors come to the result that parallel yard layouts with respect to the quay are more efficient that perpendicular layouts.

Wiese, Kliewer and Suhl (2008) and Wiese, Suhl and Kliewer (2009) adapt a mixed integer programming formulation (MIP) of a facility location problem in order to examine different layout configurations of container terminals. This does include the placement of terminal gates and tracks as well as the oriented yard blocks. The MIP formulation is solved by an optimization software. Further, discrete event simulation is used to evaluate the performance of the suggested terminal configurations.

Wiese (2009) and Wiese, Suhl and Kliewer (2010) consider the yard performance and costs of a container terminal under different possible block widths. This is in contrast to Wiese, Kliewer and Suhl (2008) and Wiese, Suhl and Kliewer (2009), where fixed block lengths are assumed and to Kim, Park and Jin (2008), where only the orientation of the blocks is considered. Wiese, Suhl and Kliewer (2010) propose a mixed-integer model in order to find optimal positions of driving lanes in a rectangular container yard. The MIP model is reformulated to a network flow model. This allows to identify efficiently optimal solutions. Further, a local search heuristic is proposed for non-rectangular instances.

In the book chapter of Wiese, Suhl and Kliewer (2011), the impact of different block configurations on the yard performance and costs is analyzed. A multi-objective optimization model is proposed. With the help of an enumeration strategy, a non-dominated solution is identified.

Basallo-Triana, et al. (2019) propose a non-linear mathematical model for the transshipment process in a container terminal. The objective is to minimize the investment and operating cost such that the terminal has enough capacity and all operations are performed within a given time window. An exhaustive enumeration procedure is implemented in order to solve this problem. The authors draw the conclusion that the container dwell time has a high impact of the performance of the terminal.

2.2.2 Simulation

Simulation can be defined as "a representation of a system with its dynamic processes in an experimentable model to reach findings which are transferable to reality" (Verein Deutscher Ingenieure, 2014, p. 3) and is therefore a suitable tool to predict the operational behavior of a system that is not yet realized. Twrdy and Beskovnik (2008) discuss that simulation is a central method to predict the productivity parameters of a planned container terminal before its realization. The simulation model is based on the considered layout, a chosen container handling system, and the related container handling processes. Since investments into an improved layout or container handling system are long-term decisions, the simulation depends on forecasting such as trends in vessel sizes, transportation demands, and container flows through the terminal. Depending on the type of the current design decision, different kinds of simulation models are used. Angeloudis and Bell (2011) differentiate in their review, among others, between simulation models that are microscopic (detailed) and macroscopic (simplified) as well as generic or focused on a small subset of operations. Dragović, Tzannatos and Park (2017) classify simulation models, among other, on whether alternative container handling systems have been evaluated, analytical models have been tried out (e.g. for scheduling), or storage policies have been tested. This indicates the wide range of questions simulation can help to answer, even though not all questions can be answered with a single simulation model. Therefore, in the following the role of simulation in the retrieved literature has been examined.

Asef-Vaziri, Khoshnevis and Rahimi (2008) present the integration of an Automated Storage and Retrieval System (ASRS) and an ALV System. The

ASRS is used as an alternative to traditional storage yards. The simulation model covers a detailed representation of the ASRS racks including the velocity profile of the storage and retrieval machine. By altering the rack structure and employing varying ALV fleet sizes and different dispatching strategies, the operational characteristics of an ASRS at a container terminal are presented.

Hubler (2010) compares several different types of conventional stacking equipment for the yard. Depending on the equipment, different layout options and possible workflows are compared. In addition, a cost comparison and a qualitative rating is conducted. The rating covers environmental impact, safety, suitability for future automation, and cost risk for construction.

Kemme (2013) sets up a large simulation study to examine the operational differences between RMG systems, i.e. Single RMG, Twin RMG, Double RMG, and Triple RMG. Depending on the system, one to three RMGs are used in one yard block which differ in their crossing abilities. These systems are tested in different environments, e.g. different yard block layouts, different container dwell times, or different container flows. The simulation study aims to create insights for decision makers.

Pachakis, Libardo and Menegazzo (2017) present the container terminal planning process of an offshore container terminal in detail. Four different storage options are compared offshore and two options onshore. In both cases, the yard layout is determined by the equipment and no alternative layouts are discussed. While simulation is used to predict the productivity, in addition aspects such as the ability to phase the works, the energy consumption and the costs of ownership are considered.

Sauri, et al. (2014) discuss when it is reasonable to invest into automated horizontal transport systems. SCs and AGVs are examined by means of simulation to obtain the required fleet size which in turn is part of the cost model. For container terminals with a high throughput and high labor costs, AGVs pay off.

Vis and Harika (2004) compare the unloading times of the ship when using AGVs and ALVs. ALVs have the advantage that if a reasonably sized buffer area exists, the horizontal transport is decoupled from stacking so that the ALV waits less at transfer point. When only considering the purchase costs and neglecting layout restrictions, the authors conclude that ALVs are cheaper since smaller fleets are sufficient.

Vis (2006) compares SCs and yard cranes for storing and retrieving containers from the storage area. Simulation is used to evaluate different arrival patterns both of vessels and from the landside as well as a varying number of rows of a yard block. Results show that the number of rows of a yard block correlates with higher storage and retrieval times making them eventually inefficient.

Altogether, these publications can be grouped into two classes. In the first group, simulation has been used to digitally experiment with innovative and therefore unpreceded solutions. The second group consists of publications that gain insights into operational characteristics of conventional equipment in order to make an informed acquisition decision between different types of equipment. In both cases, simulation enables the planner to determine the required fleet size for the desired throughput. The chosen equipment determines the yard layout which has not been a major subject of discussion in any of the publications.

3 Discussion

The retrieved literature in Section 2 covered a wide range of different long-term decisions regarding equipment and layout. In Subsection 2.1, the literature was classified according to the considered subsystems, i.e. quay side, traffic area, yard area, and hinterland connection. Furthermore, the retrieved literature has been attributed with different methods. In Subsection 2.2, the literature was presented grouped by the employed quantitative method, either mathematical optimization or simulation. In total, the literature has been looked at from three angles which provides some insights worthwhile discussing.

Regarding the considered subsystem, a great discrepancy between the different terminal areas can be seen. While 21 publications examine different equipment or layout options for the yard and 12 for the traffic area, only 5 publications do this for the quay side and only 2 papers discuss different possibilities for the rail and road interfaces. In these two publications by Wiese, Kliewer and Suhl (2008) and by Wiese, Suhl and Kliewer (2009), the hinterland connection is one of several terminal areas that are part of their model. This difference in coverage in scientific literature indicates that the hinterland is of least concern.

When weighing up different equipment or layout options, mathematical optimization and simulation are most commonly used to estimate the impact on operations each decision would have. At the same time, financial and environmental aspects need to be considered. While e.g. Pachakis, Libardo and Menegazzo (2017) describe each option with its pro and contra arguments (which has been indicated in Table as CON), e.g. Crawford-Condie and Peet (2017) aggregate a set of scores into a single score (which has been indicated with MUL in the same table). Such a score clearly indicates the option to prefer which in turn allows to optimize the decision of layout and equipment selection in a formal sense. As far as mentioned in the respective articles, this optimization process has been executed manually.

As discussed in the introduction, when developing the optimal selection for both equipment and layout, theoretically three approaches are feasible: With a fixed layout the equipment is chosen, with a fixed equipment the layout is improved, or both equipment and layout can be freely chosen. Wiese, Suhl and Kliewer (2011) state that typically the type of equipment is chosen first for the respective terminal area and later the layout is designed. The retrieved literature concurs on this point that the general business requirements determines the equipment which in turn determines the layout. In Figure 2, this process has been visualized. While the process imposes an order, in general planning activities are not truly independently (Böse, 2011). For illustration: When determining the fleet size for horizontal transport with simulation, a layout must be assumed. If, on the other hand, a layout is designed with certain yard block dimensions, this implies that for implementation some stacking equipment exists that can be efficiently used for such a kind of yard block. In summary, this sequential process model reflects the common approach to solve the intertwined problem.

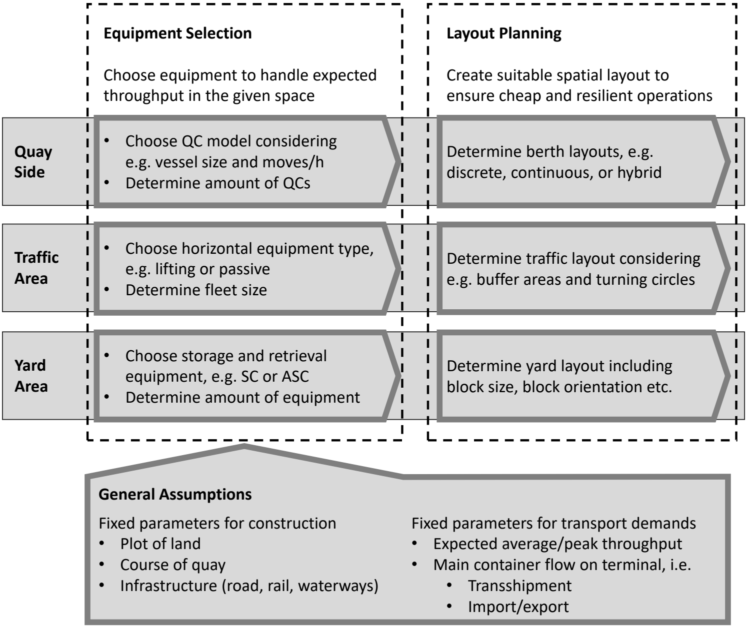

Figure 2: Order of decisions when determining equipment and layout

In Figure 2**,** only the quay side, traffic area and yard area have been considered. Due to low coverage in literature, the hinterland connection has been neglected. Both the equipment selection and layout planning are driven by general assumptions which are determined by the terminal infrastructure and transport demands. The listed assumptions are only exemplary, for further information consult e.g. Böse (2011) and Twrdy and Beskovnik (2008). In the following paragraphs, Figure 2 is discussed and examples from the retrieved literature are given. Especially the difference between mathematical optimization and simulation is worked out.

At the quay side, at modern container terminals ship-to-shore gantry cranes are used as quay cranes. Yavary, et al. (2010) simulate the performance of specific models such as quay cranes with secondary trolleys or tandem lift capability for a given scenario. The results are used as an argument for investment decisions. Meisel and Bierwirth (2011) use mathematical optimization to derive the optimal amount of quay cranes considering both costs and transportation demands.

When selecting the horizontal equipment, costs and operational performance need to be balanced. Sauri, et al. (2014) use simulation to arrive at the required fleet size for SCs and AGVs respectively. The corresponding fleet size is inserted in a cost model that determines the cheaper of the two options. Wiese et al. (2009b) use mathematical optimization for traffic layout planning as placement of terminal gates and tracks is considered in their solution method.

In the yard area, Hubler (2010) uses simulation to determine the productivity and costs of different stacking equipment, i.e. RTGs and RMGs, including different layout options. Considering a variety of further criteria, each option is assigned a combined weighted score that designates the best option. Mathematical optimization is used in a couple of publications (e.g. by Kim et al. (2008) or Wiese et al. (2010)) in order to determine the yard layout. The focus of these papers is mostly on yard block sizes and orientations.

In summary, simulation is employed when a manageable amount of different options is compared. This is especially the case in the equipment selection process. The results of a simulation study can be combined with aspects such as costs, duration of construction, environmental impact, and safety for workers. This shows that the decision for or against an equipment is not solely an economic decision but it also potentially includes company policies and governmental regulations. On the other hand, mathematical optimization is useful when the amount of options is vast and the score to optimize can be calculated automatically. This especially holds true when comparing different terminal layouts with a fixed container handling system.

4 Conclusions and Future Research Directions

In this paper, we conducted a mapping review on how decisions regarding equipment and layout are connected: Suitable container handling systems have to be selected as well as an appropriate container terminal layout has to be designed. The focus of the literature review is to regard the employed methodology with respect to how these mutually dependent decisions are considered.

The conducted literature review shows that equipment and/or layout in the yard and in the traffic area achieve more attention than at the quay side or in the hinterland. Further, mathematical optimization and simulation are the most commonly used methodologies. It is observed that the equipment selection is mostly tackled with simulation whereas mathematical optimization has its domain in layout planning, particularly in the yard. An interaction of both planning activities as well as of the two methodologies (mathematical optimization and simulation) has been rarely seen in literature. Limitations of this literature review and possible further research directions are discussed in the remainder of this chapter.

4.1 Limitations of This Literature Review

This literature review followed the approach of a mapping review (see Section 2). The details about the search process have been provided for future repeatability. For the same purpose, the analysis has been restricted to the obtained search results ignoring possible leads in the cited literature. Furthermore, in research often several synonyms coexist which makes it challenging to define proper search terms. These search terms need to lead to (close to) all publications that cover the desired topic while at the same time the amount of literature going through the latter manual screening process needs to be of reasonable size. The obtained literature was distilled into a sequential process model in Section 3 and set into context. As a consequence, additional search terms and more scientific databases could have shed a different light on this matter and more details could have been presented.

4.2 Future Research Directions

This publication investigated how the decisions regarding equipment selection and layout planning are integrated. Methodologically speaking these two topics are only loosely coupled. The previously elaborated limitations of this literature review indicate that neither the equipment selection process nor the layout planning could have been examined exhaustively. For both topics, systematic reviews (see Grant and Booth, 2009) that point out the link to the respective other topic could create new insights about how the two decisions are practically and methodologically dealt with.

Furthermore, most of the obtained literature covered design decisions regarding the yard (see Table). While some publications examined the waterside, the decision process regarding the hinterland connection was never the main subject. This leads to two questions: (1) how to best design the hinterland connection (usually truck gate and rail terminal) in terms of equipment and layout, and (2) why this has not been well covered in previous publications.

Last, the herein covered literature was discussing specific types of equipment and specific requirements on a seaport container terminal layout, which restricts the applicability of the proposed solutions to the very same domain. On the other hand, on a methodological level, the decision-making process can be compared with the design of other logistics nodes, such as rail-road container terminals or inland ports. Clausen and Kaffka (2016) have previously demonstrated the parallels between seaport and inland container ports. By pursuing these commonalities and contrasts, a method to jointly cover layout planning and equipment selection at both seaport and inland container terminals can be derived.

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