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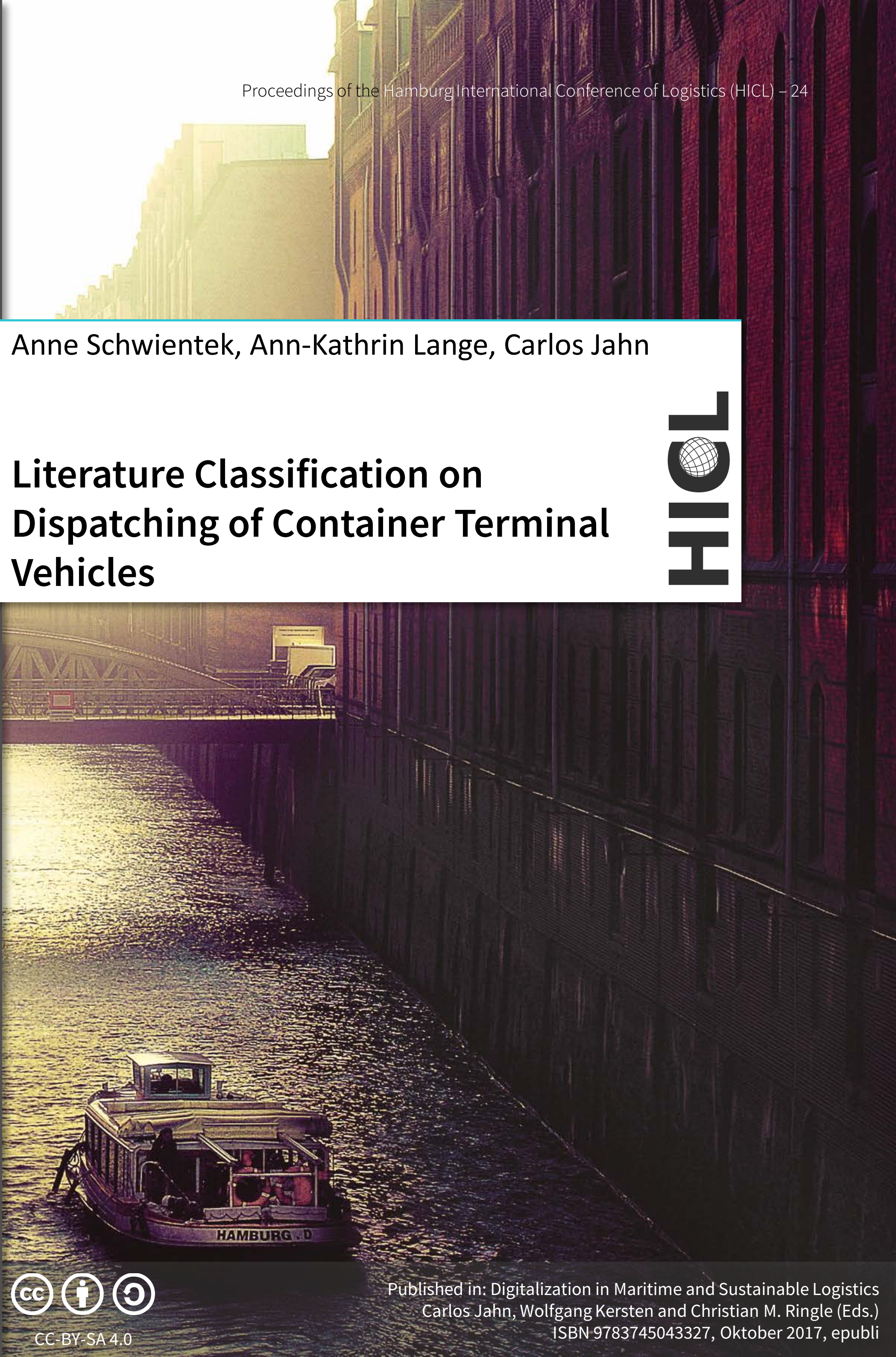

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Literature Classification on Dispatching of Container Terminal Vehicles

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Horizontal transport on container terminals represents the interface between quay and yard. Efficient transport operations are essential to improve performance and productivity. Thereby, one main decision problem is dispatching the vehicles. Despite the large amount of literature in this field, there is no classification or survey of the respective literature.

Based on an extensive survey of dispatching literature published between 2000 and 2016, a classification scheme is developed and applied to 81 scientific publications. The classification serves as a framework to propose a definition of dispatching – distinguishing it from scheduling – and to identify trends and potential for future research.

The understanding of 'dispatching' differs significantly from assigning tasks to vehicles to developing exact schedules for the vehicles. Another substantial difference is whether the dispatching problem is considered separately from other terminal operations or integrated. Influencing factors on the ranking of dispatching methods are hardly investigated.

The classification scheme provides for the first time a comprehensive background for classification of dispatching literature. It comprises a large list of criteria in three categories: problem characteristics, solution method and performance evaluation. Thereby, this paper provides a basis to derive further research activities.

Keywords: Container terminal; Horizontal transport; Literature survey and classification; Dispatching

1 Introduction

Container terminals are logistic nodes connecting sea transports of containers with the hinterland or other sea transports. For this purpose, vessels are discharged and loaded. During the discharging process of a vessel on a medium-sized to large container terminal, containers are unloaded from a vessel by quay cranes (QC), transported by vehicles to the yard area and placed in a yard block by a yard crane (YC) or straddle carrier (SC). The vessel loading process is carried out from yard to quayside respectively.

Typical equipment types for horizontal transport are terminal trucks (TT), automated guided vehicles (AGV), automated lifting vehicles (ALV) or SC. Transport equipment can be divided into active (ALV, SC) and passive (TT, AGV) equipment. Active equipment can lift a container and is able to carry out a transport tasks independently. Passive equipment has to wait for a quay or yard crane to be (un)loaded and the cranes have to wait if the passive vehicle is not yet available.

Efficient transport operations are essential to allow for optimal quay crane operations and to serve vessels as fast as possible. There are three main decision problems for horizontal transport operations (Carlo et al., 2014b, p.2): (1) Choosing the type of equipment, (2) Determining the required number of equipment, and (3) Routing and dispatching the equipment. This literature survey focuses on the last issue, especially the dispatching problem. Container transport tasks and available vehicles have to be assigned to each other most efficiently to serve the quay cranes continuously and reduce the driven distances of the vehicles as the same time.

The terms dispatching and scheduling are often used synonymously. Contrariwise, some authors see a clear difference between these terms. In that case, dispatching is usually defined as a dynamic allocation of vehicles and transport tasks when certain events occur (e.g. task accomplished, vehicle available). This is a very flexible but rather myopic approach. In contrast, scheduling is defined as calculating a detailed, static long-term schedule for container transport tasks based on estimated arrival and operations times. The schedule can be optimized using mathematical methods but is very dependent on the quality of the time estimates (Grunow et al., 2006). For the purpose of this survey, the term dispatching is used to include both ideas, following the definition from (Bian et al., 2015) who differentiate between static (scheduling) and dynamic (dispatching) dispatching.

This paper follows three objectives: (1) to develop a classification scheme for approaches to optimize dispatching in horizontal transport based on an extensive literature survey, (2) to classify 81 publications to be able to (3) determine research trends and identify potential for future research.

Therefore, the paper is structured as follows: Section 2 discusses the dispatching problem and provides information on related literature surveys. Section 3 presents information on the literature search procedure and the classification scheme. In section 4, the actual classification is given together with a literature evaluation. Section 5 comprises research trends and interesting future research areas.

2 Discussion of Dispatching Problem and Related Literature Surveys

2.1 Dispatching Problem

Dispatching in horizontal transport on container terminals has been a research topic since 15-20 years. It raised interest when the first container terminals started to automate horizontal transport using AGV. Nevertheless, also manned horizontal transport received attention from researchers in this context showing potential for optimization while in practice most non-automated terminals organize horizontal transport by dedicated dispatching (see e.g. Koo, 2013, p.2).

Dedicated dispatching is the most uncomplicated way to organize horizontal transport operations. Vehicles are organized in gangs of 4-6 and each gang is assigned to one QC. Thereby, they only conduct transport tasks for this QC. Dedicated dispatching is easy to organize although very inefficient as roughly 50% of the time the vehicles drive empty.

Dispatching follows various objectives. One objective is to serve the QC continuously by delivering or picking up containers. This results from defined vessel service times that are agreed between terminal operator and shipping company. Furthermore, QC are the most expensive equipment on a container terminal and should be utilized as much as possible. Another objective refers to the horizontal transport itself. Thereby, the driven distances should be minimized to reduce empty drives, fuel consumption, emissions, and the number of required vehicles and to maximize the equipment utilization.

2.2 Existing Literature Surveys

Vis and Koster (2003) and Steenken et al. (2004) classify decision problems in general on container terminals and provide both a large overview on terminal literature especially of the 1990s. Stahlbock and Voß (2007), Carlo et al. (2014a, 2014b, 2015) extend these and add further publications. Thereby, Carlo et al. (2014a, 2014b, 2015) investigate the three terminal areas quay side, horizontal transport and yard side separately. Kim and Lee (2015) focus on decision problem trends and place a special emphasis on Terminal Operating System (TOS) functions. Gharehgozli et al. (2016) supplement the literature surveys by an overview on innovative technologies and OR trends. Angeloudis and Bell (2011) focus on simulation models investigating container terminal operations.

Vivaldini et al. (2015), Qiu et al. (2002), Desrochers et al. (1990), Egbelu and Tanchoco (1984) offer overviews on scheduling and routing of AGVs without focusing on container terminals. Stahlbock and Voß (2008) considers especially routing problems of vehicles on container terminals. Despite the large amount of dispatching literature referring to container terminals there is no literature survey and classification focusing on this topic. This publication aims to close this gap.

3 Approach and Classification scheme

3.1 Literature Search Procedure

For the extensive literature search, several scientific databases and search engines such as Google Scholar, ScienceDirect and ResearchGate were used with the search terms dispatching or scheduling and container terminal. All publications that investigated horizontal transport operations - potentially in combination with another terminal area - were initially considered relevant and evaluated in the next step whether they actually investigated the research topic. Publications only

considering deadlock avoidance, routing or the required number of equipment were excluded. Thereby, the content and not the wording was the deciding factor. Following, during the publication analysis and classification the lists of references were evaluated to identify further publications. Only English publications were included.

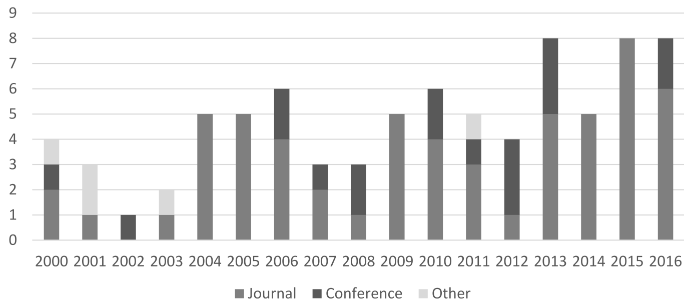

Figure 1: Relevant publications per year

The literature search produced 81 publications between 2000 and 2016 (see Figure 1). The number of papers continuously increases within that period, indicating that this is still a challenging research topic.

The 81 publications comprise 58 journal papers, 18 conference contributions and 5 other publications (research papers, dissertations). Journal paper are published in 39 different journals, most frequently OR Spectrum (8x), Transportation Research Part E: Logistics and Transportation Review (5x), and European Journal of Operational Research (4x).

3.2 Classification scheme

The classification scheme is separated in three main categories (see table 1): (1) problem characteristics, (2) solution approach, and (3) performance evaluation.

The first category problem characteristics refers to all classification parameters that describe the problem considered in the respective publication. These parameters are term, outcome, dispatching objective, system boundary and equipment. Term refers to the word that is used to describe the problem. Outcome considers the issue that the terms are defined differently and describes what is produced by the chosen dispatching method. Dispatching objective refers to the terminal performance measure that is supposed to be optimized. System boundary describes the terminal area(s) that is/are optimized in the respective publication. Equipment includes the type and capacity of the dispatched equipment.

The second category solution approach refers to all classification parameters that describe the approach that is used to solve the dispatching problem considered in the publication. These parameters are planning horizon, mathematical problem formulation, exact algorithm, dispatching method(s), and method development and / or comparison. The planning horizon describes the time perspective when a dispatching decision is taken. The planning horizon varies between real-time and a long-term dispatching plan for several hours. The parameter mathematical problem formulation describes whether the publication presents an explicit problem formulation containing objective function and side conditions. Accordingly, exact algorithm refers to the question whether the formulated problem is solved using an exact algorithm finding the best solution. Dispatching methods considers the methods investigated in the respective publication such as dedicated dispatching, priority rules or heuristics. Lastly, method development and / or comparison describes whether the authors develop an own dispatching method, compare the method with others or whether they collect typical methods and compare them.

The third category performance evaluation refers to all classification parameters that describe the implementation and testing of the solution approach. The category includes the parameters evaluation method, specific terminal, and sensitivity analysis. The first parameter evaluation method refers to the investigation approach. Specific terminal describes whether a real container terminal is investigated (usually a simplified version) or whether hypothetical numbers are used. Lastly, the sensitivity analysis parameter describes which terminal parameters are varied in the sensitivity analysis.

In the following, the classification scheme is applied to 81 publications. Thereby, the subsections are organized according to the three classification categories problem characteristics, solution approach, and performance evaluation.

Table 1: Classification scheme

Problem characteristics	Solution approach	Performance evaluation
Term	Planning horizon	Evaluation method
Outcome	Math. problem formulation	Specific terminal
Dispatching objective	Exact algorithm	Sensitivity analysis
System boundary	Dispatching method(s)	
Equipment	Method development and/or comparison	

4 Literature Classification

4.1 Problem characteristics

The first parameter in this classification category is the term that is used to describe the problem. Thereby, the most prominent appearance is significant for the classification. For example, if dispatching is used in the publication title and scheduling later on in the text, the publication is classified to the parameter value dispatching. Possible values are dispatching, scheduling and other (e.g. assigning, routing, deploying). In total, 32 publications use the term dispatching, 38 publications use the term scheduling and 11 publications use another term. As figure 2 shows, the use of the term dispatching stays relatively constant while the term scheduling increases lately.

The second classification parameter is the outcome of decision problem which can be an allocation, a sequence or a schedule. In total, 29 publications produce a dynamic allocation of tasks and equipment, 21 create a task sequence and 31 produce a detailed schedule for the equipment.

Table 2 shows the interrelation between the term that is used in the respective publication and the outcome of the dispatching process. There is a cluster of publications using the term dispatching leading to the outcome allocation or sequence. There is also a cluster of publications using the term scheduling aiming to the outcome schedule. Publications using other terms such as assigning, routing, deploying show the outcome allocation of sequence. Nevertheless, there are 11 publications that do not fit into these clusters.

The third parameter in the first category is the dispatching objective, i.e. the terminal parameter that is supposed to be optimized. 57 publications focus on one dispatching objective, accordingly 24 publications focus on more than one objective. The dispatching objective usually refers to a specific object as vessel, QC, vehicle or task. Vessel-related objectives are e.g. to minimize the makespan or the departure delay. QC-related objective are e.g. to maximize productivity or to minimize QC wait time. Vehicle-related objectives are e.g. to maximize productivity or to minimize wait time, travel distance or fleet size. Task-related objectives are usually to minimize wait time or delay. Other objectives that fit to these categories are to minimize the wait time of customers trucks, to make best use of space or to maximize the YC throughput. Most publications focus on vessel-related (38x) or vehicle-related (29x) objectives.

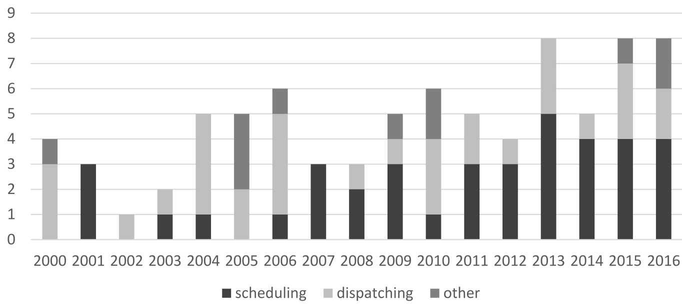

Figure 2: Number of publications per year using the respective term

Table 2: Correlation between name of term and outcome

	Allocation	Sequence	Schedule
Dispatching	20	10	2
Scheduling	2	7	29
other	7	4	0

The fourth parameter refers to the system boundaries of the respective publication. The closest boundary is to focus on horizontal transportation (HT) separately (44 publications). In contrast, the broadest boundary is to integrate horizontal transport, quayside and yard operations (HT+Q+Y; 12 publications). In between are partly integrated investigations setting the system boundaries to horizontal transport plus either quay side (HT+Q; 4 publications) or yard side (HT+Y; 21 publications).

Figure 3 shows that a separate boundary is applied continuously during the 17 years. The number of papers applying the integrated perspective increases lately, especially the publications taking the partly integrated perspective with the quay side.

Table 3 shows the number of publications that use the respective term (dispatching, scheduling, other) and define the respective system boundary (HT, HT+Q+Y, HT+Q, HT+Y). Publications using the term dispatching focus in most cases on HT separately. In contrast, in publications using the term scheduling all system boundaries are represented.

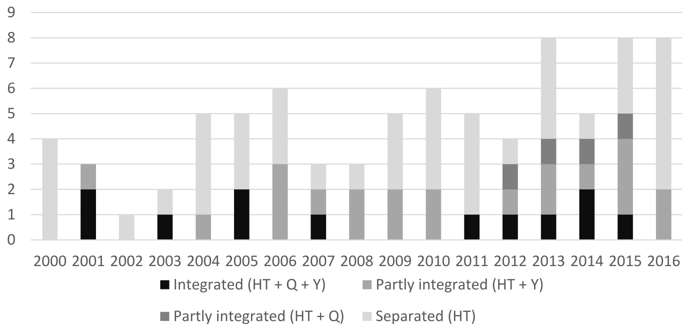

Figure 3: Number of publications per year defining the respective system boundary

Table 3: Correlation between term and system boundary

	HT	HT+Q+Y	HT+Q	HT+Y
Dispatching	28	1	1	2
Scheduling	9	9	3	17
Other	7	2	0	2

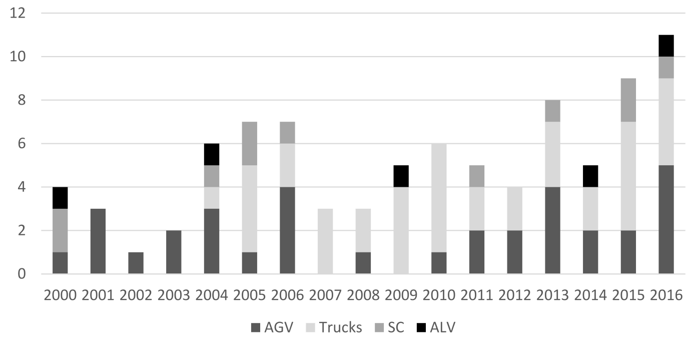

Figure 4: Number of publications per year evaluating the respective equipment

The fifth parameter describes the equipment type and capacity that is considered in the respective publication. AGV are represented in 34 publications, TT in 39 publications, SC in 11 publications and ALV in 5 publications. Only 6 publications consider dual or multiple load equipment.

Figure 4 shows the equipment distribution over time. Between 2000 and 2005/2006 the focus is on AGV, in the following years TT gained interest. Since 2011, the distribution of equipment is relatively balanced.

Figure 5 presents the classification overview for the first category.

Table 4: Abbreviations used in figure 5

A - Allocation	O - other	SQ - Sequence
AG - AGV	Q - Quay crane	T - Task
D - Dispatching	QY - Quay/Yard	TT - Terminal Truck
DM - Dual/multiple load	S - Schedule/-ing	V - Vessel
HT - Horizontal transport	SL - SC or ALV	VH - Vehicle

Publication	Term			Outcome			Dispatching Objective					Boundary		Equipment			
	D	S	O	A	SQ	S	V	Q	VH	T	O	HT	QY	SC	TT	AG	DM
(Ahn et al., 2007)		■				■		■					■		■		
(Angeloudis and Bell, 2010)			■		■			■				■				■	
(Bae and Kim, 2000)	■			■			■		■			■				■	
(Behera et al., 2000)			■	■							■	■		■			
(Bian et al., 2014)	■			■					■			■		■			
(Bian et al., 2015)	■			■							■	■				■	
(Bish et al., 2001)		■		■			■						■			■	
(Bish, 2003)		■		■			■						■			■	
(Bish et al., 2005)	■				■		■					■				■	
(Böse et al., 2000)	■				■			■	■			■		■			
(Briskorn et al., 2006)	■			■				■				■				■	
(Briskorn and Hartmann, 2006)	■			■				■				■				■	
(Cao et al., 2008)		■				■	■						■		■		
(Cao et al., 2010)		■			■		■						■		■		
(Pan et al.)	■				■				■			■			■		
(Chen et al., 2007)		■				■	■						■		■		
(Chen et al., 2013)		■				■	■						■		■		
(Chen et al., 2016)	■			■			■		■			■			■		
(Cheng et al., 2005)	■			■					■			■				■	
(Choe et al., 2012)		■				■		■			■		■		■		
(Choe et al., 2016)	■			■				■			■	■				■	
(Cordeau et al., 2015)			■		■				■				■	■	■		■
(Corman et al., 2016)		■				■	■					■				■	
(Dulebenets, 2016)			■	■					■			■		■	■	■	
(Garro et al., 2015)	■				■				■			■		■			
(Grunow et al., 2004)	■				■		■					■				■	■
(Grunow et al., 2006)	■				■		■					■				■	■
(Hartmann, 2004)		■				■				■			■	■		■	
(He et al., 2015)		■				■	■				■		■		■		
(Homayouni et al., 2012)		■			■			■	■				■			■	
(Homayouni and Tang, 2013)		■				■		■	■				■			■	
(Homayouni et al., 2014)		■				■		■	■				■			■	
(Kaveshgar and Huynh, 2015)		■			■		■						■		■		
(Kim and Bae, 2004)	■			■				■				■				■	
(Kim et al., 2013)	■			■				■	■		■	■				■	
(Klerides and Hadjiconstantinou, 2011)	■			■						■		■				■	■
(Koo, 2013)	■			■			■					■				■	
(Koster et al., 2004)	■			■						■		■		■			

Figure 5: Classification table (Problem category), continued on next page

Publication	Term			Outcome			Dispatching Objective					Boundary		Equipment			
	D	S	O	A	SQ	S	V	Q	VH	T	O	HT	QY	SC	TT	AG	DM
(Kozan and Preston, 2006)		■				■	■						■		■	■	
(Lee et al., 2008)		■				■			■				■		■		
(Lee et al., 2009b)		■				■			■				■		■		
(Lee et al., 2009a)		■				■			■	■			■		■		
(Lee et al., 2010)	■				■		■						■		■		
(Li and Vairaktarakis, 2004)	■			■			■					■			■		
(Li et al., 2015)		■				■	■						■		■		
(Liu and Ioannou, 2002)	■			■				■	■		■	■				■	
(Lu and Jeng, 2006)	■					■	■						■		■		
(Luo and Wu, 2015)		■				■	■						■			■	
(Luo et al., 2016)		■				■	■						■			■	
(Meer, op. 2000)	■			■						■		■		■			
(Meersmans and Wagelmans, 2001b)		■				■	■						■			■	
(Meersmans and Wagelmans, 2001a)		■				■	■						■			■	
(Moussi et al., 2011)		■				■			■			■		■			
(Murty et al., 2005a)			■	■			■		■		■		■	■	■		
(Murty et al., 2005b)			■	■			■		■		■		■	■	■		
(Ng et al., 2007)		■				■	■					■			■		
(Nguyen and Kim, 2009)	■					■		■	■			■		■			
(Niu et al., 2016)		■				■	■			■		■	■		■		
(Nishimura et al., 2005)			■		■				■			■			■		■
(Park et al., 2009)			■	■			■					■			■		
(Petering, 2010)			■	■				■				■			■		■
(Rashidi and Tsang, 2011)		■				■			■	■		■				■	
(Skinner et al., 2013)		■				■			■			■		■			
(Song et al., 2008)	■			■					■			■				■	
(Song and Huang, 2013)	■			■						■		■				■	
(Soriguera and Espinet, 2006)			■	■						■			■	■			
(Tang et al., 2014)		■			■		■						■		■		
(Tao and Qiu, 2015)	■			■			■		■			■			■		
(Tsai et al., 2016)		■				■					■	■			■		
(Wang, 2011)	■				■		■						■		■		
(Wang et al., 2013)		■				■			■				■		■		
(Wang et al., 2014)		■				■			■				■		■		
(Xin et al., 2014)		■			■		■				■		■			■	
(Xing et al., 2012)	■				■			■					■			■	
(Xue et al., 2013)		■				■	■		■				■		■		
(Yu et al., 2010)	■			■			■					■			■		
(Zaghdoud et al., 2016)			■		■		■					■				■	
(Zeng et al., 2009)		■			■		■					■			■		
(Zeng et al., 2011)		■				■	■					■			■		
(Zhang et al., 2005)	■				■			■				■			■		
(Zheng et al., 2012)		■			■						■	■	■		■		

Classification table (Problem category), continuation

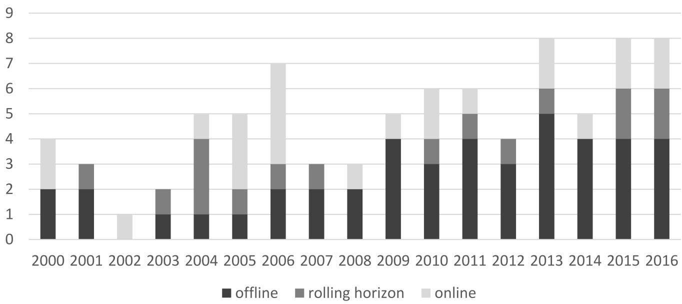

Figure 5: Number of publications per year using the respective planning horizon

4.2 Solution approach

The first parameter in this category is the planning horizon with the parameters online, rolling horizon, and offline. It refers to the period of time between the moment when the decision is taken und the moment when the last task of the planning period is executed. Therefore, online means that the task is executed right after the dispatching decision is taken. Offline implies that the planning horizon comprises several hours. Rolling horizon is a hybrid form. It refers to a planning period that is refreshed frequently but includes several hours. 23 publications investigate online planning, 44 publications investigate offline planning and 16 publications investigate the hybrid rolling horizon. Figure 5 shows the number of publications per year that investigate the respective planning horizon. While online and rolling horizon are represented in a relatively constant number of publications per year, offline planning seems to gain more and more interest.

The second and third parameter in this category are mathematical problem formulation and exact algorithm. An explicit problem formulation containing objective function and side conditions is presented by 61 publications. 31 publications solve the problem using an exact algorithm. However, this is very time consuming and congruently it is explained that this solution approach is not applicable to real container terminals.

As fourth parameter, there are various dispatching methods represented with a diverging complexity. The in practice easiest method dedicated dispatching is used in 14 publications, usually to show the potential for improvement when other methods are used. The next group of method called priority rule are often greedy methods which aim to prioritize the task assignment based on time or distance parameters. Examples are e.g. nearest vehicle, FCFS, longest wait time. 37 publications apply priority rules. The third group of dispatching methods includes optimization techniques such as genetic algorithms or local search heuristics. 61 publications apply these methods, of which 28 test genetic algorithms as largest sub-group. Only 3 publications do not apply any of these methods. They formulate a mathematical model and solve it using CPLEX. All methods are used continuously during the years.

The fifth parameter in this category is method development and/or comparison. 58 publications develop an own dispatching method, 50 publications compare either their developed method with other methods (29x) or collect several methods to compare them (21x).

Figure 6 presents the classification overview for the second category.

Table 5: Abbrevations used in figure 6

C - Comparison	OFF - Offline	PR - Priority Rule
DD - Dedicated Disp.	OM - Own method	R - Ranking
E - Exact Algorithm	ON - Online	RH - Rolling Horizon
H - Heuristic	PF - Problem Formulation	

Publication	Planning Horizon			Problem formulation and method					Development / comparison		
	ON	RH	OFF	PF	E	DD	PR	H	OM	C	R
(Ahn et al., 2007)		■					■	■	■	■	
(Angeloudis and Bell, 2010)		■		■			■	■	■	■	
(Bae and Kim, 2000)			■	■	■	■		■	■		
(Behera et al., 2000)	■						■				■
(Bian et al., 2014)	■			■	■			■			■
(Bian et al., 2015)	■			■				■			■
(Bish et al., 2001)			■	■			■	■	■	■	
(Bish, 2003)			■	■				■	■		
(Bish et al., 2005)	■						■				■
(Böse et al., 2000)			■	■		■	■	■			■
(Briskorn et al., 2006)	■			■	■		■	■			■
(Briskorn and Hartmann, 2006)	■			■				■	■		
(Cao et al., 2008)			■	■	■			■			■
(Cao et al., 2010)			■	■				■			■
(Pan et al.)			■	■				■	■		
(Chen et al., 2007)			■	■	■			■	■		
(Chen et al., 2013)			■	■	■			■	■		
(Chen et al., 2016)		■		■				■	■	■	
(Cheng et al., 2005)		■		■	■		■		■		
(Choe et al., 2012)		■		■			■	■	■	■	
(Choe et al., 2016)	■							■	■	■	
(Cordeau et al., 2015)		■		■				■	■	■	
(Corman et al., 2016)		■		■	■		■	■			■
(Dulebenets, 2016)	■						■				■
(Garro et al., 2015)		■		■		■	■		■	■	
(Grunow et al., 2004)		■		■	■		■		■		
(Grunow et al., 2006)	■	■					■		■	■	
(Hartmann, 2004)		■		■			■	■			■
(He et al., 2015)			■	■	■	■		■	■	■	
(Homayouni et al., 2012)			■	■	■		■		■	■	
(Homayouni and Tang, 2013)			■	■	■		■		■		
(Homayouni et al., 2014)			■	■	■			■			■
(Kaveshgar and Huynh, 2015)			■	■	■			■	■		
(Kim and Bae, 2004)		■		■			■	■	■	■	
(Kim et al., 2013)	■			■			■	■	■	■	
(Klerides and Hadjiconstantinou, 2011)		■		■	■						
(Koo, 2013)	■					■	■				■
(Koster et al., 2004)	■						■				■
(Kozan and Preston, 2006)			■	■				■			■
(Lee et al., 2008)			■	■			■	■	■	■	
(Lee et al., 2009b)			■	■			■	■	■	■	
(Lee et al., 2009a)			■	■	■			■	■		
(Lee et al., 2010)			■	■	■			■			■

Figure 6: Classification table (Solution approach), continued on next page

Publication	Planning Horizon			Problem formulation and method					Development / comparison		
	ON	RH	OFF	PF	E	DD	PR	H	OM	C	R
(Li and Vairaktarakis, 2004)			X	X			X	X	X	X	
(Li et al., 2015)			X	X				X	X		
(Liu and Ioannou, 2002)	X						X				X
(Lu and Jeng, 2006)			X	X		X		X	X	X	
(Luo and Wu, 2015)			X	X	X			X	X		
(Luo et al., 2016)			X	X	X			X	X		
(Meer, op. 2000)	X						X	X			X
(Meersmans and Wagelmans, 2001b)		X				X	X	X	X	X	
(Meersmans and Wagelmans, 2001a)			X		X			X	X		
(Moussi et al., 2011)			X	X				X			X
(Murty et al., 2005a)	X					X		X	X		
(Murty et al., 2005b)	X					X		X	X		
(Ng et al., 2007)			X	X	X			X	X		
(Nguyen and Kim, 2009)			X	X	X			X	X		
(Niu et al., 2016)			X	X				X	X	X	
(Nishimura et al., 2005)		X		X	X	X		X	X		
(Park et al., 2009)	X					X	X				X
(Petering, 2010)	X					X		X	X	X	
(Rashidi and Tsang, 2011)			X	X	X		X		X		
(Skinner et al., 2013)			X	X			X	X	X	X	
(Song et al., 2008)	X							X	X	X	
(Song and Huang, 2013)		X		X			X	X	X	X	
(Soriguera and Espinet, 2006)	X			X			X		X		
(Tang et al., 2014)			X	X	X			X	X	X	
(Tao and Qiu, 2015)	X						X		X	X	
(Tsai et al., 2016)			X	X							
(Wang, 2011)	X		X	X	X		X	X	X		X
(Wang et al., 2013)			X	X	X			X	X		
(Wang et al., 2014)			X	X	X			X	X		
(Xin et al., 2014)			X	X	X						
(Xing et al., 2012)			X	X	X			X	X	X	
(Xue et al., 2013)			X	X	X		X	X	X		
(Yu et al., 2010)	X							X	X		
(Zaghdoud et al., 2016)			X	X				X	X	X	
(Zeng et al., 2009)			X	X		X	X	X	X	X	
(Zeng et al., 2011)			X					X	X		
(Zhang et al., 2005)			X	X			X		X		
(Zheng et al., 2012)			X	X		X		X	X	X	

Classification table (Solution approach), continuation

4.3 Implementation and evaluation

The first parameter in this category is the evaluation method which can be simulation or numerical experiments. 24 publications evaluate using a simulation model, 55 publications conduct numerical experiments and 2 publications implement both methods.

Next parameter is specific terminal which describes whether the evaluation study is conducted for a real terminal or tested with hypothetical numbers. 33 publications refer to a specific terminal. Figure 6 shows that most of these terminals are located in Europe (16 publications) and Asia (14 publications). European terminals are located in Hamburg, Rotterdam, Gioia Tauro, Le Havre, and Barcelona. Asian terminals are amongst others located in Shanghai, Busan, Hong Kong, Singapore.

The third parameter in this category considers the sensitivity analysis of the respective publication. A lot of publications vary the equipment number in the sensitivity analysis, mostly the number of vehicles, but also the number of QC and YC (see figure 7) which usually correlates with a variation of the terminal size. The second most varied parameter is the number of tasks considered in the evaluation. Planning parameters being varied are e.g. the frequency of rescheduling (in case of a rolling horizon approach) or the configuration of a genetic algorithm. Other problem features are e.g. the time between jobs, time between vessels, container position on the vessel, QC load/discharge combination, number of consecutive QC jobs of the same type. Layout-related parameters in the sensitivity analysis are e.g. distance between quay and yard side, the number of blocks, stacking height in the yard. Stochasticity refers to the degree of stochasticity of vehicle travel time or QC operation time. This is rarely investigated similar to the vehicle capacity or speed.

Figure 8 presents the classification overview for the third category.

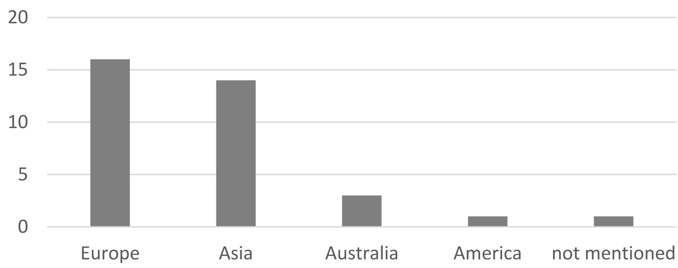

Figure 6: Number of publications referring to a terminal on the respective continent

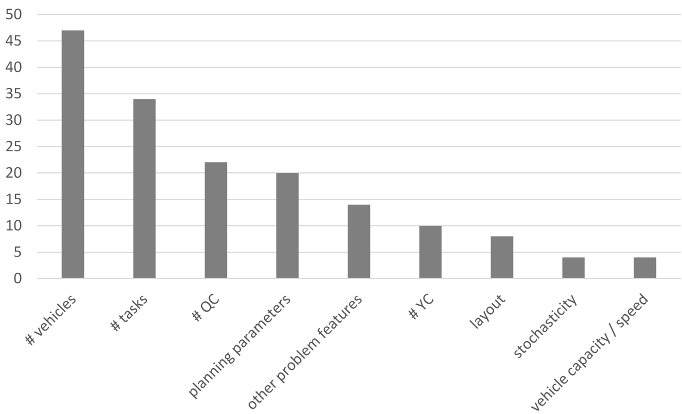

Figure 7: Number of publications varying the respective terminal parameter in the sensitivity analysis

Table 6: Abbrevations used in figure 8

L - Layout	SI - Simulation	VH - No. of vehicles
NE - Num. experiments	SP - Specific terminal	Y - No. of YC
OP - Other problem feat.	ST - Stoachsticity	
PP - Planning parameter	T - No. of tasks	
Q - No. of QC	VC - Vehicle capacity	

Publication	Evaluation method			Sensitivity analysis								
	SI	NE	SP	VH	Q	Y	T	OP	PP	L	ST	VC
(Ahn et al., 2007)	X								X			
(Angeloudis and Bell, 2010)		X	X	X								
(Bae and Kim, 2000)		X		X	X							
(Behera et al., 2000)	X		X	X				X				X
(Bian et al., 2014)		X					X					
(Bian et al., 2015)		X					X					
(Bish et al., 2001)		X		X			X					
(Bish, 2003)		X		X			X			X	X	
(Bish et al., 2005)		X										
(Böse et al., 2000)		X	X					X		X		
(Briskorn et al., 2006)	X		X					X	X			
(Briskorn and Hartmann, 2006)	X		X	X				X				
(Cao et al., 2008)		X					X					
(Cao et al., 2010)		X	X	X		X	X					
(Pan et al.)		X	X									
(Chen et al., 2007)		X	X	X	X	X	X					
(Chen et al., 2013)		X	X	X	X	X	X					
(Chen et al., 2016)		X		X	X	X		X				
(Cheng et al., 2005)	X		X	X				X				
(Choe et al., 2012)	X								X			
(Choe et al., 2016)	X			X				X				
(Cordeau et al., 2015)		X	X	X								
(Corman et al., 2016)		X		X			X					
(Dulebenets, 2016)	X				X			X				
(Garro et al., 2015)	X		X	X	X		X	X	X			
(Grunow et al., 2004)	X	X	X	X	X		X			X		
(Grunow et al., 2006)	X		X	X	X		X			X	X	X
(Hartmann, 2004)		X	X						X			
(He et al., 2015)		X		X	X	X	X					
(Homayouni et al., 2012)		X		X	X		X		X			
(Homayouni and Tang, 2013)		X		X	X		X		X			
(Homayouni et al., 2014)		X		X	X		X		X			
(Kaveshgar and Huynh, 2015)		X		X	X		X		X			
(Kim and Bae, 2004)	X			X					X		X	
(Kim et al., 2013)	X			X								
(Klerides and Hadjiconstantinou, 2011)		X		X	X		X		X			X
(Koo, 2013)		X		X								
(Koster et al., 2004)	X		X	X					X			
(Kozan and Preston, 2006)		X	X	X						X		
(Lee et al., 2008)		X					X					
(Lee et al., 2009b)		X						X				
(Lee et al., 2009a)		X						X				
(Lee et al., 2010)		X		X		X	X					

Figure 8: Classification table (Implementation and evaluation), continued on next page

Publication	Evaluation method			Sensitivity analysis								
	SI	NE	SP	VH	Q	Y	T	OP	PP	L	ST	VC
(Li and Vairaktarakis, 2004)		X	X	X			X					
(Li et al., 2015)		X										
(Liu and Ioannou, 2002)	X			X								
(Lu and Jeng, 2006)		X	X	X								
(Luo and Wu, 2015)		X		X	X	X	X		X			
(Luo et al., 2016)		X		X	X	X	X		X			
(Meer, op. 2000)	X		X									
(Meersmans and Wagelmans, 2001b)	X		X						X		X	
(Meersmans and Wagelmans, 2001a)	X		X	X	X	X	X					
(Moussi et al., 2011)		X	X				X		X			
(Murty et al., 2005a)		X	X	X								
(Murty et al., 2005b)		X	X	X								
(Ng et al., 2007)		X		X			X		X			
(Nguyen and Kim, 2009)		X		X	X		X			X		
(Niu et al., 2016)		X										
(Nishimura et al., 2005)		X	X		X			X		X		X
(Park et al., 2009)	X		X									
(Petering, 2010)	X			X		X				X		
(Rashidi and Tsang, 2011)	X						X					
(Skinner et al., 2013)	X		X				X					
(Song et al., 2008)		X	X									
(Song and Huang, 2013)	X			X					X			
(Soriguera and Espinet, 2006)	X		X									
(Tang et al., 2014)		X		X	X		X					
(Tao and Qiu, 2015)	X		X	X				X				
(Tsai et al., 2016)		X		X								
(Wang, 2011)	X	X										
(Wang et al., 2013)		X							X			
(Wang et al., 2014)		X	X									
(Xin et al., 2014)		X	X					X				
(Xing et al., 2012)		X					X					
(Xue et al., 2013)		X		X	X		X		X			
(Yu et al., 2010)		X										
(Zaghdoud et al., 2016)		X		X			X					
(Zeng et al., 2009)		X		X	X		X					
(Zeng et al., 2011)		X										
(Zhang et al., 2005)		X										
(Zheng et al., 2012)		X										

Classification table (Implementation and evaluation), continuation

5 Conclusion and Future Research

This paper develops a classification scheme for vehicle dispatching on container terminals and applies it to 81 papers. Based on the classification, developments in the research area are identified. There are two main approaches. On the one hand, there is the dispatching approach that aims at a vehicle-task allocation or sequence, focuses on the system boundary horizontal transport separately, and applies a dynamic online solution method. On the other hand, there is the scheduling approach that aims at a detailed schedule for the vehicles, potentially extends the system boundary by quay and / or yard side, and applies a static offline solution method. Of course, there are a lot of hybrid approaches in between.

A lot of publications develop an own dispatching method or compare a few methods for a specific container terminal. A couple of authors vary several terminal parameters within the sensitivity analysis. Zeng et al. (2009) and Liu and Ioannou (2002) show that the number of available vehicles affects the ranking of dispatching methods. Until today, there is no publication analyzing the interdependency between terminal parameters and method performance systematically. Furthermore, dispatching methods perform differently if they are evaluated based on different objectives (see e.g. Dulebenets, 2016). For example, one method is more appropriate to minimize a vessels makespan while another method is more appropriate to reduce the energy consumption. This is an interesting research topic for the future.

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