Literature Classification on Container Transport Systems for Inter-terminal Transportation

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Abstract. The upward trend in global containerized trade is predicted to continue. In addition, increasing ship sizes, growing demand for port-centered value added services and environmental considerations are creating challenges for handling port internal traffic, also referred to as inter-terminal transportation (ITT). Container transports are often carried out by truck, which may lead to congestion in the port area. Due to increasing demand for greater efficiency and for more sustainable and environmentally friendly approaches, new transport solutions receive more attention. In order to strengthen their competitiveness, seaports consider digitalization-driven innovations and technologies and intelligent new concepts to improve the quality and efficiency of port activities, including ITT. The main purpose of the paper is to highlight different approaches to conventional means of land-based transport and future trends.

Based on an extensive literature survey, a classification scheme was developed and applied to scientific publications. The classification scheme comprises a multitude of criteria, including methodology and research objective of the publication and the degree of implementation and automation of the discussed approaches. In addition, challenging subject areas that might help the discussion of the topic in the future, are identified. The findings show that solutions discussed in literature often provide conceptual and very theoretic outlines. It is particularly noticeable that the publications do not deal comprehensively with the integration into existing logistics systems. This shows research perspectives in most diverse areas including the effective process integration at nodes and edges of innovative ITT networks.

Keywords: Inter-terminal transportation · Container transport · Literature survey · Classification

1 Motivation

With regard to positive trends in the global economy, the United Nations Conference on Trade and Development (UNCTAD) is forecasting a continuous annual growth rate of 3.8% of global maritime trade between 2018 and 2023, predicting the greatest

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growth for containerized and dry bulk goods [1]. Moreover, with the introduction of ever larger container vessels, maritime transport chains are becoming more complex. Container vessels enter ports with lower frequency but larger volumes, which causes peaks in various phases of container handling, including truck dispatching [2]. Besides, the growth in truck traffic is also associated with an increasing demand for port-centered, value-added logistics services. In addition, intensive seaport competition and spatial restrictions of ports require efficient means of handling port traffic. Objectives such as minimizing transport delays, time and costs, high capacity utilization rates and minimizing empty runs are pursued [3].

At the same time, environmental protection is becoming more important for sustainable growth in transport and logistics. Due to greater environmental awareness and legal requirements, the commitment to CO_2-reduced logistics is increasing, for example by using environmentally friendly modes of transport [4].

Digitalization offers many new opportunities in maritime logistics to increase productivity, efficiency and sustainability. Smart ports as a concept, for example, aim to use modern information technologies to improve planning and management within and between ports. This requires investments in technologies and collaborations needed for information exchange [5]. Ports use these modern technologies to provide better operational control and meet new challenges in maintaining safe, secure and energy-efficient facilities that reduce their environmental impact [6]. For example, truck appointment systems at container terminals are used to improve the efficiency of transport operations [7].

In addition, the use of intelligent infrastructure and automation can be taken into account to enable alternative solutions to conventional container transports by truck. At present, neither more efficient and environmentally friendly water-based nor land-based transport modes are used to transfer relatively high quantities within terminals/service facilities. Focus of this paper lies on alternative solutions to conventional land-based transports and highlighting challenges of their integration in seaports. Since water-based transport is structurally limited in its connectivity of nodes/facilities and moves with quay-cranes are very costly and often represent a bottleneck at terminals, water-based solutions are not generally suitable. Nevertheless, there are innovative water-based approaches such as the port feeder barge, which is equipped with its own container crane [8], or waterborne automated guided vehicles [9]. The objective of this work is to provide a structured classification of literature in order to identify relevant and challenging research fields.

Therefore, this paper is organized as follows. A conceptual delimitation of ITT is introduced in Sect. 2. Then in Sect. 3, based on an extensive literature survey, we create a scheme to classify relevant literature. General challenging subject areas that might help the discussion of the topic in future research are proposed in Sect. 4, followed by a conclusion in Sect. 5.

2 Introduction to Inter-terminal Transportation

Geerlings et al. [10] provide an overview of ports and maritime networks, including basic knowledge of definitions, actors and functions as well as diverse concepts of ports. Steenken et al. [11] describe logistic processes and operations in container terminals including further information on transport and handling equipment.

ITT describes the movement of containers between terminals within a port that serve container ships, railways, inland vessels and other forms of hinterland transport [12]. Further definitions also assign ITT to any type of land- and water-based transport of containers and cargo between organizationally separate areas within a seaport and from and to dry ports [3].

In some ports, the demand for ITT results from separately located container terminals. In addition, there are dedicated rail and inland waterway terminals, which bundle freight from various actors within the port for intermodal transportation. Moreover, there are facilities that offer value-added services, which can include labelling, packaging, inspection and customizing activities [13]. Besides, ITT networks link service facilities such as container repair stations, empty container depots and customs facilities. These procedures can be mandatory and therefore imply ITT [3].

In the following, container transport systems for ITT are characterized by enabling land-based transfers of containerized units between points of origin and destination, which can be defined as nodes that are linked by edges. The network of nodes may include terminals and service facilities within the port as well as inland hubs and dry ports near the port.

3 Literature Review and Classification

There are various approaches in literature to design the transport of containers between terminals, ranging from conventional systems to future trends. Several authors investigate different system approaches with the help of simulation or stochastic models, while considering manned and automated systems. Duinkerken et al. [14], Schroër et al. [15] and Gharehgozli et al. [16], inter alia, use simulation to compare different container transport systems. Those systems are based on existing handling equipment for horizontal container transport in container terminals. Duinkerken et al. [14] focus on an object-oriented simulation of multi-trailer systems (MTS), automated guided vehicles (AGV) and automated lift vehicles (ALV) to move containers between two nodes with a maximum distance of 6,000 m. Schroër et al. [15] investigate alternatives for container transport between the terminals Maasvlakte 1 and Maasvlakte 2 in the Port of Rotterdam using discrete event simulation. Gharehgozli et al. [16] also concentrate on MTS, AGV and ALV with a dedicated infrastructure and additionally consider the transport of containers by manned trucks on public roads.

Other publications deal with innovative transport systems. For example, van der Heijden [17] developed a concept for unmanned, automatic transport of containers. The containers are loaded onto trailers, which are pulled by electric vehicles guided by a special rail system. In addition, there are publications dealing with the underground transport of containers. Stein et al. [32] present a future traffic scenario in which modules transport the containers autonomously through tunnels.

Furthermore, there are publications that give an overview of ITT. Heilig and Voß [3] analyze research works concerning ITT to discuss the recent state-of-the-art and research progress, focusing on publications regarding decision analytics as well as innovative information technologies, comprehensively. They consider an assessment of simulation studies as well as optimization and information system approaches. Besides, they suggest future research topics to be linked with ITT like transport scheduling, vehicle routing, collaborative planning and resource sharing, information technologies, green logistics, deployment models and application areas. Shin et al. [18] provide an overview of latest examples and trends related to automated intermodal freight transport system technologies, which mainly aim to relief the infrastructure and to provide a more sustainable, environmentally friendly solution. They give directions for future technical developments. Hu et al. [19] provide a systematic review of existing research on ITT planning in port areas and the hinterland, identifying several research gaps like multi-modality of ITT systems, which are rarely studied. The reviewed papers illustrate the scientific relevance of ITT, however, they tend to cover the technical components of general freight transport systems or the planning and controlling of ITT.

This paper, distinguished from the above, focuses mainly on alternative transport systems. Those are either (1) improving transport on the road infrastructure by using other vehicles than conventional trucks, or (2) shifting container transport volumes from road to other traffic modes (e.g. rail); that may be more efficient, eco-friendly, reduce congestion and/or even facilitate improved logistics solutions.

3.1 Classification Scheme

After giving a brief introduction into the topic we analyze relevant publications in the field of container transport systems of ITT in order to extensively reflect the progress of research and the current state of the art. The literature search identified 20 relevant publications between 1995 and 2019, which are presented in Table 2.

The classification scheme is separated in ten categories, shown in Table 1: *Methodology, Port related, System, Degree of automation, Infrastructure, Dedicated infrastructure, Underground, Maximum yearly movements, Objective of the paper, and Degree of implementation*.

While *Methodology* describes the reviewed author's procedure, *Port related* examines whether the publications refer to container transports between terminals or other nodes and *System* describes the type of transport vehicles used. If more than one system is addressed in one publication, those are classified individually. In addition, the *Degree of automation* (manned or automatic vehicles) and whether the system is designed for the underground transport of containers (*Underground*) is taken into account. Moreover, the *Infrastructure* is considered and whether the system requires their own infrastructure (*Dedicated infrastructure*). *Maximum yearly movements* is subdivided into *rather high*, which defines an annual volume of more than 3 million TEU, *rather low* if it is less. *Depending on parameters*, means that in the publication the maximum container turnover of the system was not specified and is scalable. Rather, the performance of the system depends on the number of vehicles used, for example. Finally, the underlying objectives of the publication (*Objective of the paper*) and the degree of maturity of the system (*Degree of implementation*) are considered.

3.2 Classification Tables

In the following, Table 1 shows the classification categories with the possible specifications. For overview purposes, the individual specifications of the categories are assigned to numbers, which are used in the classification table.

Table 1. Classification categories with the possible specifications

Category	#	Specification	Category	#	Specification
Methodology	1	Concept	*Infrastructure*	1	Road
	2	Simulation-based study		2	Rail
	3	Mathematical model		3	Other
Port reference	1	Yes	*Dedicated infrastructure*	1	Yes
	2	No		2	No
System	1	Multi trailer system	*Underground*	1	Yes
	2	Automated guided vehicle		2	No
	3	Automated lifting vehicle			
	4	Conventional trucks			
	5	Other systems			
Degree of automation	1	Automated	*Maximum yearly movements*	1	Rather high
	2	Manned		2	Depending on parameters
				3	Rather low
Objective of the paper	1	Increase handling	*Degree of implementation*	1	Conceptual
	2	Reduce emissions		2	Pilot operations (planned)
	3	Relieve infrastructure		3	Implemented
	4	Reduce costs			

It should be noted that the status of implementation is assessed according to the current status of the respective paper. If no specification of a category is selected, then the information basis was not sufficient for an assignment. In the following table, gray fields symbolize that the specification applies, multiple choice is possible.

It becomes evident that different methodologies are used to approach the topic, whereby the publications found mainly relate to ports. However, the processes of integration into the port (connection of nodes, security purposes, etc.) were not particularly taken into account; rather, transport volumes and networks were used as data

Table 2. Classification table

	Methodology			Port reference		System					Degree of automation		Infrastructure			Dedicated infrastructure		Underground		Maximum yearly movements			Objective of the paper				Degree of implementation		
	1	2	3	1	2	1	2	3	4	5	1	2	1	2	3	1	2	1	2	1	2	3	1	2	3	4	1	2	3
van der Heijden et al. (1995)	X				X					X	X				X	X			X	X					X			X	
Pielage (2001)	X				X		X				X		X			X			X						X			X	
	X				X		X				X		X			X		X							X			X	
	X				X					X	X			X		X		X							X			X	
Ottjes (2002)		X		X			X				X		X			X			X		X		X				X		
Hansen (2004)	X			X						X	X			X			X		X			X	X			X	X		
Liu (2004)	X			X						X	X				X	X		X		X					X		X		
Duinkerken et al. (2006)		X		X		X					X		X			X			X		X					X	X		
		X		X			X					X	X			X			X		X					X	X		
		X		X				X				X	X			X			X		X					X	X		
Ottjes (2006)		X		X			X				X		X			X			X		X		X				X		
Zhang et al. (2006)		X		X					X		X		X			X			X		X		X				X		
Vernimmen et al. (2007)	X			X						X	X				X	X		X				X	X				X		
	X			X			X				X		X			X		X				X	X				X		
	X			X						X	X			X		X		X				X	X				X		
Winkelmans (2010)	X			X						X	X			X		X		X				X	X	X			X		
Roh (2011)	X			X						X	X			X		X		X		X				X		X	X		
Roop et al. (2011)	X			X						X	X				X	X			X					X	X			X	
Mishra et al. (2013)			X	X			X				X		X			X			X		X		X				X		
			X	X				X			X		X			X			X		X		X				X		
			X	X		X							X			X			X		X		X				X		
Nieuwkoop et al. (2014)			X	X		X						X	X			X			X		X		X				X		
			X	X			X				X		X			X			X		X		X				X		
			X	X				X			X		X			X			X		X		X				X		
			X	X						X		X			X		X		X		X		X				X		
Schroër et al. (2014)		X		X			X				X		X			X			X		X		X				X		
		X		X				X			X		X			X			X		X		X				X		
		X		X		X						X	X			X			X		X		X				X		
		X		X						X		X			X	X			X		X		X				X		
Stein et al. (2014)	X				X					X	X		X			X		X			X			X	X		X		
Tierney et al. (2014)			X	X		X					X		X			X			X		X				X		X		
			X	X						X	X				X		X		X		X				X		X		
			X	X			X				X		X			X			X		X				X		X		
			X	X				X				X	X			X			X		X				X		X		
Spruijt et al. (2017)	X			X					X		X		X			X			X		X	X		X			X		
Gharehgozli et al. (2017)		X		X					X			X	X				X		X		X					X	X		
		X		X			X				X		X			X			X		X					X	X		
		X		X		X						X	X			X			X		X					X	X		
Gao et al. (2019)		X	X						X		X		X			X		X			X				X		X		

basis (e.g. Tierney et al. [12], Schroër et al. [15]). The means of transport are often based on existing port equipment such as AGV, ALV and MTS. In addition, there are studies that deal with rail-guided systems that project existing and innovative approaches onto container transport (e.g. van der Heijden et al. [17], Vernimmen et al. [26]).

Automated solutions are often considered, mainly with focus on technical feasibility or efficiency improvement, less on integration in existing processes and connection possibilities. Dedicated infrastructures are often taken into account, whereby a sufficient availability of space in the port area is assumed. In order to address space problems, some publications focused on underground solutions (e.g. Stein et al. [32], Winkelmans [27]).

The transport volume that can be handled by a transport system must meet the requirements of individual ports. The maximum yearly movements specification shows that a wide variety of overall volumes can be transported. The publications pursue a broad range of objectives, although it is noticeable that the most common aim is to increase the handling volume. Finally, it can be noted that the vast majority of publications still deal with the problem in a conceptual way.

4 Research Perspectives

The examination of the classification table has revealed general gaps in research from which research perspectives are subsequently derived. Therefore, the following section deals generically with research topics, which consider challenges regarding the integration of more efficient and/or autonomous container transport systems for ITT.

4.1 General

Literature research has shown that many systems are in different phases of implementation. Moreover, some systems were not explicitly intended for container transport in port areas but could possibly be adapted to the given problem. Ports are diverse areas of application and adaptation is most likely necessary anyway. The existing infra- and superstructure has to be considered, as well as the integration into existing IT systems. Furthermore, deployment models (e.g. by third-party operators, participating nodes, hauliers) should be taken into account.

Safety considerations need to be addressed, also to promote acceptance of a system within the port and wider society. This applies in particular to autonomous processes, especially in mixed traffic with conventional vehicles or at interfaces with non-automated processes. Additionally, logistic and IT processes need to be secured, since they involve various actors which might need to intensify their cooperation, e.g. by implementing new IT interfaces and exchanging real time data. High investments, construction projects and the elimination of existing structures should be legitimated by the reduction of logistics costs, which improves the competitiveness of a port, or by environmental arguments (e.g. most of the reviewed systems are electrically powered).

The connection of a dry port or a hub in the hinterland to ITT systems is currently not sufficiently discussed in literature. The scalability of the solutions is important, as the development of transport volumes is difficult to predict. Moreover, expansion possibilities are beneficial as well as the flexibility to integrate or adapt new intelligent and innovative systems. Therefore, solutions should be evaluated in combination with e.g. collaborative planning techniques.

4.2 Process Integration at the Nodes

Many of the presented publications do not sufficiently address the connection to existing logistic nodes. However, systems, which simplify the loading and unloading process at the nodes or even make it obsolete, are to be emphasized. Especially due to short transport routes within the port, handling processes have a great impact on overall process costs and time. Large operators, such as the main container terminals within a port, should therefore be equipped with an efficient handling solution and automated gate processes should be considered. Moreover, the integration of existing handling equipment and information systems at the nodes should be taken into account. Especially actors with fewer transport quantities, like relatively small container packing stations or value-added-service facilities, do not necessarily allow a dedicated linkage to ITT systems. Simplified, cost-effective and space-saving handling at the interface at each actors' node is required. The system should to be integrated as seamlessly as possible into the existing processes.

4.3 Process Integration at the Edges

Some systems aim to separate the container transport from public infrastructure to reduce congestions. There are mainly three approaches: by using elevated forms of transport as well as underground transport and dedicated, non-public, roads. Furthermore, solutions for a more efficient utilization of existing infrastructure are considered (e.g. platooning, the use of AGV on public roads, route optimization). These different approaches require different amounts of available space in the port area and pose different construction challenges. In addition, these approaches intervene to varying degrees in port processes. In addition, it must be questioned how durable the individual systems are and to what extent the infrastructure can be used flexibly.

Some of the publications describe transport systems designed to handle a large quantity of node-to-node container transports, which are not generally suitable for shorter route length and lower volumes. Furthermore, it should be borne in mind that dangerous goods or refrigerated containers are also transported in the port. Therefore, it is worthwhile to evaluate the suitability of the concepts and, if necessary, to outline possible adaptations.

5 Conclusions

Seaports facing increasing transport volumes and competitive pressure seek for efficient solutions to handle ITT. Many of the publications provide conceptual and very theoretic outlines. By classifying relevant literature, this paper highlights different aspects from publications between 1995 and 2019 and provides a generic outlook on research topics to be considered in the future. It is generally noticeable that the publications do not deal comprehensively with the integration into existing logistics systems. This paper is a first attempt to reveal gaps that hamper successful implementation in the maritime environment. Further publications should focus on individual research perspectives in detail in order to develop comprehensive concepts.

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