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Automizing the manual link in maritime supply chains? An analysis of twistlock handling automation in container terminals

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ABSTRACT

The study at hand elaborates on potential barriers, prerequisites and optimization potentials for the automation of the twistlock handling process in container terminals. A case analysis enlightens latest automation developments of this essential task in container transport. Eight experts from different organizations in maritime logistics and seaport operations were interviewed in a qualitative multiple-case research design. The interviews were evaluated by qualitative-quantitative content analysis with MAXQDA software.

Automated twistlock handling systems are hardly implemented, although they represent the missing link between other container handling technology in the automated container transport. The study reveals that most implementation barriers consist of technological issues, followed by economic and strategic barriers. The study identifies implementation strategies and their key success and shows that safety improvements and cost reductions are major benefits of this automation. An innovation framework for this field of automation is conceptualized as scientific contribution. Practical implications include recommendations for relevant stakeholders in container logistics.

1. Introduction

Container ports worldwide have seen remarkable growth since the introduction of containerized trade in 1956 to about 2 bn tons loaded in 2018 (UNCTAD, 2019). The ports originating from handling general cargo and break bulk in the early days are now home to marine container terminals (CT) with huge handling facilities for standardized containers. As the amount of globally transported standard twenty-foot equivalent units (TEU) containers continuously increases to about 150 million TEU in 2018 (UNCTAD, 2019), growing trade volumes and ship sizes demand ever larger capacities from CTs (Baird, 2006; De Oliveira and Cariou, 2015). Pressure on port-handling capacity and volume peaks resulting from mega-sized ships and reduced service frequency cause disruption to liner operations on the landside at ports (UNCTAD, 2019). As competition between terminals intensifies, shipping lines request their ships to be loaded and unloaded at fastest possible times in order to minimize the costly time ships spent in port, to reduce port fees and to allow them to stay on tight schedules while operating at lower, more fuel-efficient ship speeds (Stahlbock and Voss, 2008).[1] In addition, requirements of operational safety, speed and cost efficiency grow continuously (Bauk et al., 2015). An estimated 793 million TEUs were handled in container ports worldwide and infrastructure investments aim at extending the cargo-handling capacity and increasing port efficiency through automation (UNCTAD, 2019). However, increasing capacity and efficiency is by no means a simple task and expanding present terminals is often limited or not possible due to ports being embedded into urban or commercial

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[1] According to Tran and Haasis (2015), the daily time charter rate of a 4,250 TEU vessel accounted for $17,775 in 2010 and even $33,375 in the prosperous year 2007.

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areas (Boer and Saanen, 2012). Thus, terminals need to make the most efficient use of land and resources available to avoid port congestion (Cullinane and Wang, 2006).

Since the 1990s, terminals have embraced automation as an instrument to increase their capacities. As a result, a trend of fully automated CTs was introduced (Martín-Soberón et al., 2014). Container transport has become a complex activity, comprising a multitude of sub-processes for transport, securing, stowage and monitoring of containers. Today, many of these sub-processes are already automated by, e.g., automatic guided vehicles (AGVs) or driverless cranes thereby eliminating human intervention and increasing efficiency (Yang and Shen, 2013). Loading and unloading containers on and off ships by means of ship-to-shore (STS) cranes thereby represents a key activity, called cargo operations in modern CTs which includes the sub-process of coning and deconing, also called twistlock (TL) handling. A TL is a securing device used to physically connect and secure containers stacked on top of each other on board of container ships.

Generally, securing of containers is referred to as lashing in the marine industry. TL handling is carried out below the STS crane by dock workers, so-called lashers, who remove TLs from or insert TLs into the container during loading and unloading operations. Securing and lashing containers on ship decks is a difficult operation that causes great problems during loading and discharge (Andersson, 1999). A quayside container crane requires at least two stevedores for manual unlocking work and many stevedores must carry out the simple and repetitive manual procedure when loading or discharging a large container vessel (Zhang et al., 2015). This illustrates that fixing and removing TLs is “the weakest link for port automation and the most difficult automation part in the whole port automation field” and, thus, merits becoming an important topic of scientific studies and practitioners’ agendas (Ma et al., 2014a, p. 2729, Chellappa, 2011). Hence, solutions to close the automation gap in CT operations already exist or are under development. Several companies have made attempts to automate coning and deconing. The expected efficiency gains that would result from automated TL handling sound promising: The time required for TL coning and deconing is practically eliminated and a single trained operator can support several ATLH units compared to two persons per container that are required for manual TL handling (Kalmar, 2015). However, automated twistlock handling (ATLH) did not accomplish to relieve lashers from conducting the tedious manual work in a hazardous port environment (Liang et al., 2015). By contrast, investigations show that ATLH is hardly adapted and that manual TL handling still is the prevalent method (Zhang et al., 2015; Ma et al., 2014a; Chellappa, 2011).

The question arises why such promising technologies have not received broad acceptance in the industry and what needs to be done to achieve this goal. The study at hand aims at exploring and capturing these circumstances empirically by qualitative case study research. Semi-structured expert interviews are conducted to identify potential barriers, prerequisites and optimization potentials for the automation of the twistlock handling process in container terminals. The interviews are evaluated by content analysis and developed further into a conceptual framework for ATLH.

The remainder of this paper is structured as follows. Section 2 provides background information on maritime container logistics and reviews related literature. The research method and aspects of scientific rigor are addressed in Section 3. The results of the study are presented in Section 4 and discussed in Section 5. Concluding remarks on summarized findings, limitations and future research prospects are given in the last section.

2. Background

2.1. Global container trade in maritime logistics

Over the last 50 years seaborne trade has seen a remarkable development with shipping accounting for a share ranging between 80 and 90 per cent of trade and representing 60-70 % of worldwide trade value of the goods handled (UNCTAD, 2018 p. 4). Total freight transported in maritime trade has more than quadrupled within the last 50 years to approx. 11 billion tons of freight in 2018 (UNCTAD, 2019). This development has mainly been driven by the increasing importance of intra-industrial trade and the emergence of globalized production processes and supply chains (Song and Lee, 2009).

Maritime cargo types include containers, (liquid or break) bulk goods, and (dry or general) cargo. Amplified by the transition from classic general cargo to standardized transport containers for multimodal transport, also known as containerization, maritime container transport has risen steadily over the last 40 years and nowadays accounts for about one quarter of international maritime trade (UNCTAD, 2018, 2019). Over the last two decades, global container trade increased by 5.8 % CAGR with double-digit growth rates in the 2000s and a considerable decline in 2008 caused by the global financial and economic crisis (see Fig. 1).

The most important global container trade routes named mainlanes East-West with 40% share of global container trade connect North America, Europe and Asia in a westerly and easterly direction (UNCTAD, 2019). Further trade routes include the non-mainlane East-West (13% share), the South-South routes (12% share) or the North-South routes (8% share) and intraregional trade accounts for about one quarter of global container trade. Along named trade routes the world’s largest and most complex container ports are managed and operated by port authorities and other terminal operators that serve the import, export and transshipment of containerized goods.[2]

About 65% of global container throughput is handled in Asia, followed by Europe with approx. 26% and North and Latin America with less than 10% each. In 2017, a majority of the world’s 20 largest container ports, measured by container throughput, are located in Asia (Shanghai, Shenzhen and Ningbo-Zhoushan (China), Singapore, Busan (South Korea) and Hong Kong) while only five of the

[2] Note that one seaport may be home to several CTs, each operating independently from each other.

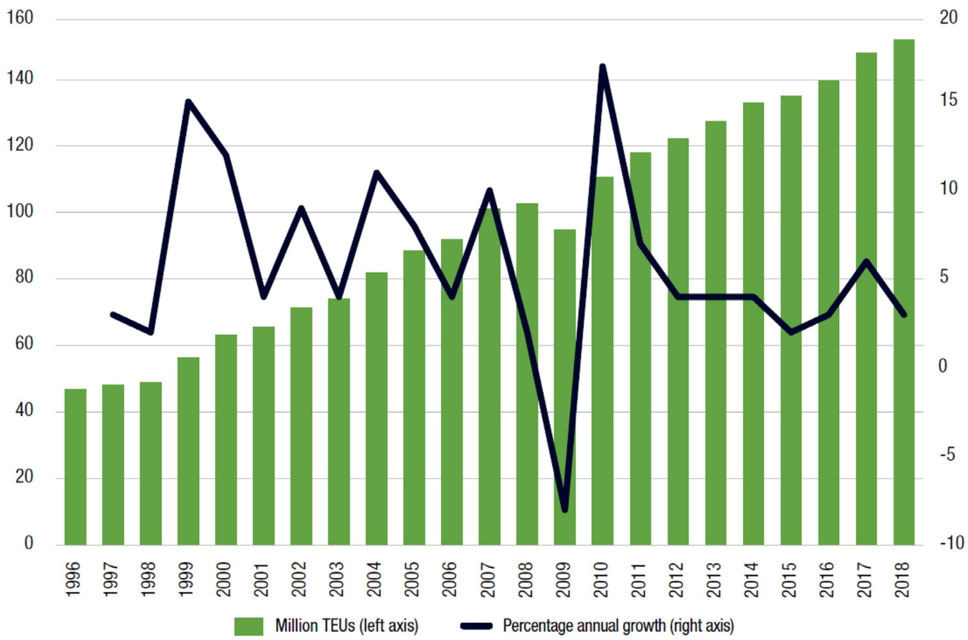

Fig. 1. Global container trade 1996-2018 (Source: UNCTAD secretariat calculations, based on data from MDS Transmodal World Cargo Database, UNCTAD, 2019, p. 12).

largest ports were located outside the Asian region with Dubai being the only location in the top 10 (UNCTAD, 2018). Many of these ports are embedded in existing infrastructure of commercial or urban areas and, thus, can hardly be expanded (Hinkka et al., 2018).

Since “a container port becomes more efficient in moving cargo to and from ships (…), the container ships that call at the port are expected to increase in size” (Talley, 2009, p. 64). The average capacity of newly built container ships continuously grows. The average capacity of a container ship currently accounts for approx. 6,000 - 7,000 TEU and ultra large container ships with more than 18.000 TEU represent a third of the newly built container ship capacity (Merk, 2018). Larger ships result in higher port charges for cargo handling charges and harbor fees. Consequently, terminal operators seek to attract larger ship calls by deploying greater capacities while shipping lines aim at minimizing their ships’ time in port which in turn can be achieved by greater TEU handling capacities of CTs. As a result, increasing capacity and reducing costs through efficiency gains is of growing importance for container ports and, thus, stimulates investments into automation systems (Kozan, 1994; Bauk et al., 2015). Moreover, supply chain collaboration between seaports, port users and other stakeholders in maritime logistics is required to maintain and improve port performance (Ascencio et al., 2014; Seo et al., 2016).

2.2. *Container operations*

Today’s containers are based on ISO standard 668 which defines dimensions, construction, and weight of the container (Bültjer and Schulze, 2013). Most important components are the corner castings, also known as corner fittings, which are hollow steel cuboids located at each corner of a container with openings on the sides as well as on the underside or top. Corner castings are used to fasten individual containers together, to secure the container on board of container ships and to attach it to other means of transport such as trucks and cranes (Bültjer and Schulze, 2013).

On a container ship, the containers are stowed on deck with up to eleven levels and below the deck with up to nine levels (Steenken et al., 2004; Bensalhia, 2019). The stacked containers are physically connected with twistlocks, i.e. twist-and-plug connectors with a weight of 5-10 kg (Liang et al., 2015). A sufficient number of TLs is stowed in gear box containers aboard the ship and, thus, is always available. For utilization, a TL is inserted into the corner casting of a container and serves as a vertical connection between stacked containers on deck (Zhang et al., 2015). In addition, containers on deck are secured with lashing bars while the cargo holds below deck are fitted with cell guides on the walls of a container ship that secure the containers against slippage and may render the TLs below deck obsolete, e.g. when fourty-foot containers are loaded (Bültjer and Schulze, 2013). Although all TLs fit in standardized corner castings, they differ greatly in shape, weight and type (Ma et al., 2014a). In total, more than 30 different types of TLs are in use worldwide. Regarding the degree of automation, TLs can be grouped into three categories: (1) Manual twistlocks, which must be manually unlocked and locked before containers can be unloaded or secured; (2) semi-automatic twistlocks (SAT), which lock automatically when the container is set down on the ship, but must be unlocked manually before unloading and (3) fully automatic twistlocks (FAT) which are automatically locked by the container’s own weight and automatically unlocked by the container crane’s tearing force (Bültjer and Schulze, 2013).

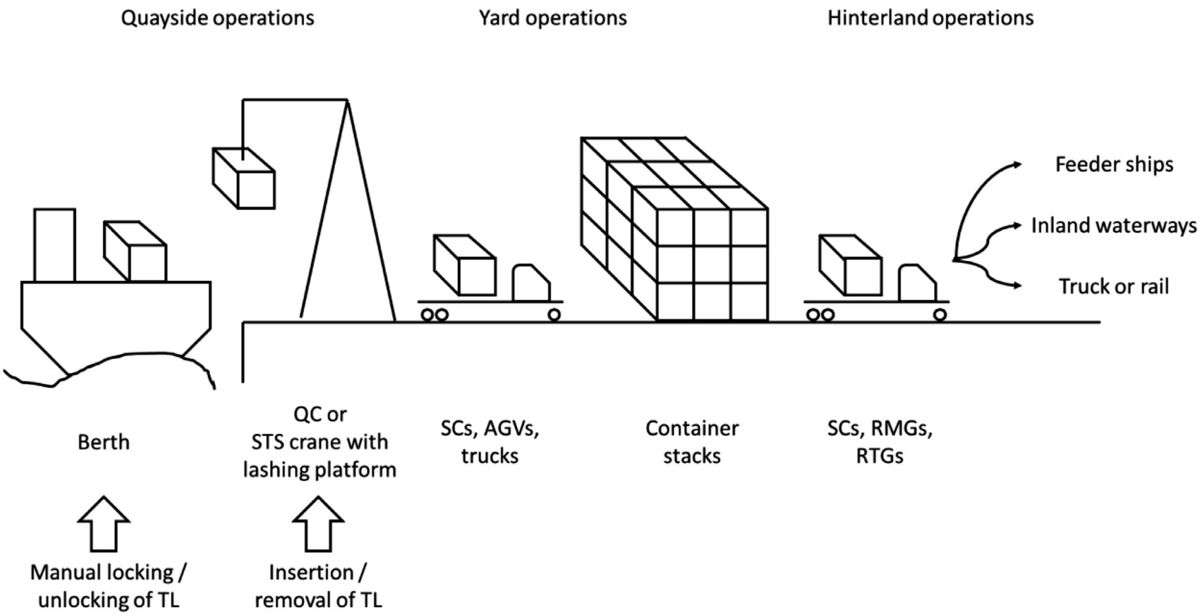

Fig. 2. Structures and processes of CT operations.

Modern CTs are complex systems segmented into three operational areas (Steenken et al., 2004): (1) The quayside operations (also known as seaside operations) at the interface between land and sea for the loading and unloading of ships. (2) The yard, i.e. the handling area for the storage, transshipment, import or export of containers. (3) The hinterland operations (also known as landside operations) at the intermodal interface between maritime logistics and other modes of transport. A large variety of processes is executed in these operational areas. For better understanding of the study at hand, processes and structures of CT operations are illustrated in Fig. 2 and described in the following.

When a container ship moors at a berth of the CT, lashers come onboard to manually unlock the TLs between the individual container layers on deck before the unloading process can begin.[3] After unlocking the TLs, the containers are unloaded by STS cranes, also called quay cranes (QC). The unlocked TLs are still connected to the upper container and remain in its lower corner castings when the container is lifted from the ship. Depending on the port equipment, the containers are then transported horizontally through the yard by AGVs, straddle carriers (SCs) or trucks with container chassis (Bültjer and Schulze, 2013).

Before onward transport of containers takes place, the TLs must be removed from the container and returned to the ship after completion of cargo operations. The container is picked up by the STS crane, lifted from the ship, lowered over the pier and held approx. 1.5 meters above the ground so that lashers can remove the TLs from the container and temporarily store them nearby. Afterwards the container is put down on the ground, picked up by an AGV, SC or truck and transported to its next destination.[4] A container can be placed for TL handling on an additional lashing platform if a double-trolley STS crane is deployed. In such systems, the first trolley transports the container from the ship to the lashing platform where TLs are removed or inserted by lashers and the second trolley transports the container between the lashing platform and the yard vehicles. Since both trolleys operate independently from each other and from the TL handling process, the TLs can be inserted on or removed from the lashing platform independently of the trolley movement. Thus, the lashing platform eliminates the process of holding the container above the ground.[5]

The containers are then transported to the container stacks, i.e. storage areas on the terminal yard, where containers are either stored in the stacks for further transshipment or taken to a multimodal terminal for distribution to the hinterland (Vis and De Koster, 2003). The transport of containers within the stacks is carried out by means of SCs, smaller rail-mounted gantry cranes (RMGs), or rubber-tired gantry cranes (RTGs) (Steenken et al., 2004). The containers may then be further distributed by a feeder ship, inland waterway vessel, truck or rail (Bültjer and Schulze, 2013).

The loading process of a container ship is the reversion of the unloading process. Containers may arrive at an intermodal terminal by various modes of transport before they are transported towards the stack by SCs, AGVs or trucks. Containers may also arrive by another container ship and be stored in the stack for transshipment before they are forwarded using the respective vehicle. Prior to a ship's arrival, a pre-stowage is made at the terminal, i.e. containers to be loaded are brought into the area of the berth for faster cargo operations (Bültjer and Schulze, 2013). For the actual loading process, the container is positioned below the STS crane, lifted

[3] If a ship uses FATs, this manual process of physical disconnection of the containers is omitted.

[4] Note: The container does not necessarily have to be put on the ground. In some cases, the container may be loaded directly onto the vehicle after the TLs have been removed.

[5] Note: Some single-trolley STS cranes may also be equipped with such a lashing platform.

and held above the ground so that lashers can insert the TLs into the corner castings.[6] When double-trolley STS cranes are in use, the TLs are inserted at the lashing platform. The whole process iterates after the container is loaded onto the ship. The dock workers gather the required quantity of TLs from the gear box containers on board the ship and return this box to the ship when all loading and unloading operations are completed. After securing the containers with lashing bars, the ship is eventually ready for departure.

It should be noted that fees or charges, so-called port tariffs, are payable for all the processes described above. These can vary depending on the CT and are an elementary part of the price and cost structure for shipping lines, terminal operators and freight forwarders. Those tariffs apply for e.g. movements, lashing or stowage of containers.

2.3. Automation in container terminals and TL handling

Apart from building port expansions, automation is an effective measure to increase CT capacity especially due to its high degree of standardization (Martín-Soberón et al., 2014). Technical efficiency obtained by, e.g., automated equipment is a prerequisite for cost efficiency and profit maximization (Talley, 2009). Automation is often associated with technological or management innovation and accompanied by process improvement and cost reduction (Lin, 2007; Martín-Soberón et al., 2014).

Benefits of automation include the improvement of operational performance through the more efficient use of existing capacities and the improvement of occupational health and safety (OHS) by eliminating human intervention (Monfort, 2011; Walters et al., 2020). Human intervention can be reduced by automation of activities, information channels or decision-making processes. The ECT Delta Terminal in the Port of Rotterdam, pioneer in this domain, introduced the concept of automated terminals in 1993 and started the continuing trend of automation (Martín-Soberón et al., 2014). Automation can shorten the ship turnaround time, thereby reducing operating costs and port fees and improving container throughput (Stahlbock and Voß, 2008; Talley, 2009; Carlo et al., 2015). Disadvantages of automation include reduced flexibility in operational planning, considerable investment requirements and possible conflicts with trade unions due to substitution of manual labor (Martín-Soberón et al., 2014).

In recent literature, the term automated container terminal usually refers to automated container handling in the yard, in particular use of AGVs, autonomous SCs or autonomous stacking cranes (ASC) (Gupta et al., 2017; Kumawat and Roy, 2020; Vis et al., 2001). The automation of STS cranes movements is another option, but due to high operational complexity STS crane automation is least developed and seldom implemented. Only selected sub-processes are automated. Depending on whether sub-processes or entire process chains are automated, a CT is either automated or semi-automated and either newly designed or upgraded from an existing one (Martín-Soberón et al., 2014).

Apart from STS cranes, the TL handling is an exception in CT automation. This process remains completely dependent on human intervention and is estimated to be carried out about 2 billion times a year worldwide (RAM SMAG Lifting Technologies, 2019). TL handling carried out by lashers may result in inconsistent automation along the transport chain of a CT and, thus, may constitute a capacity bottleneck and represents the missing link in automation (Ma et al., 2014a). Moreover, the work of the lashers in this process is considered greatly unergonomic, extremely risky and dangerous (Zhang et al., 2015; Liang et al., 2015). Walters and Wadswirth (2012, p. 44) reveal that "injury rates among lashers, mostly in relation to manual handling, were far higher than those among other groups of workers and that of the average for the terminal as a whole".

Considering all the above, possible goals of ATLH may be defined as safety improvements, closing the automation chain, reduction of labor cost and risk mitigation. Various manufacturers develop systems to automate this process and have applied for patents. Although test phases have been carried out, no large-scale use of such equipment has been observed so far. Possible reasons for this include high investment costs for equipment, low handling speed resulting in decreased container throughput and inability of equipment to handle all types of TLs (Liang et al., 2015).

2.4. Related scientific literature

A large number of studies investigate operations research (OR) applications and analytical approaches to CT operations (see, e.g., Bierwirth and Meisel, 2010, 2015, for related literature reviews) and automation in CTs (see, e.g., Macharis and Bontekoning, 2004; Steenken et al., 2004; or Stahlbock and Voß, 2008, for related literature reviews). Zhang et al. (2013) optimize parameters for yard transport and STS cranes in small and medium-sized CTs. Saanen et al. (2003) simulate automated container transport chains from ship to stack and observe that advancing automation is the right concept for the future. In these studies, the TL handling automation as a possible bottleneck in CT automation remains widely unconsidered and system solutions for ATLH are omitted.

A variety of studies assesses processes and infrastructure in CTs, but none of these studies cover the detailed sub-process of TL handling. Vis and De Koster (2003) comprehensively illustrate processes in automated and manual CTs, describe port equipment used for container handling and identify related decision problems which can be solved by OR methods. It is emphasized that optimization potentials can only be realized if all involved container handling equipment is included in the optimization process. Hess and Hess (2015) minimize cost, service time and operations resources in ship's cargo handling but without considering effects of TL automation. Carlo et al. (2015) discuss trends and developments in quayside operations and examine problems of berth distribution, crane allocation and yard transport automation. The authors identify manual TL handling as a time-consuming and labor-intensive process and explain that mechanisms for efficient TL handling could result in considerable time savings. Gharehgozli et al. (2016) analyze innovative technologies and new OR models for CTs, but without addressing the incomplete automation in TL handling.

[6] When using SATs or FATs, the TLs are automatically locked and secured by the container weight when the containers are stacked on top of each other on the ship. When using manual TLs, the TLs must be locked by lashers after containers are loaded.

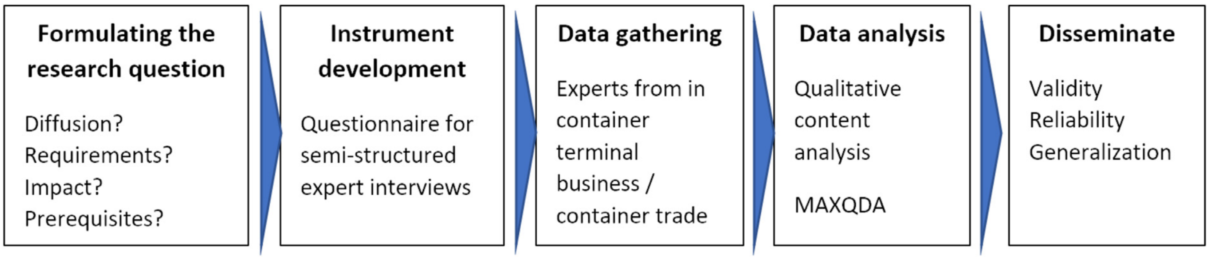

Fig. 3. Case study research process (based on Stuart et al. 2002, p. 420).

Gharehgozli et al. (2019) examine future scenarios of container trade and transport and futuristic concepts such as floating terminals and mobile STS cranes. The study describes the current state of CTs in detail with attention being drawn on the layout of CTs mainly, but without mentioning TL handling.

Echelmeyer et al. (2008) address general questions about automation in logistics and identify gaps in the automation of general logistics processes. Other studies that elaborate on the specific topic of TL handling point towards the dangerous and mostly unproductive work in manual TL handling by dock workers and present technical concept for a TL-gripping device (Klein Breteler, 2003; Ma et al., 2013, 2014; Liang et al., 2015; Zhang et al., 2015). Several studies also illustrate difficulties in automating TL handling processes (Klein Breteler, 2003; Ma et al., 2013; Liang et al., 2015). Identified challenges arise from a large variety of different TLs, missing standardization of shape and size, the mechanical problems and the high weight of TLs. Despite the focused investigation of ATLH, no study addresses economic implications or implementation aspects of such systems.

Based on a case study of Finnish ports, Hinkka et al. (2016) investigate the extent to which technological trends affect the training of dock workers. The study identifies increased occupational safety requirements and growing demands in dealing with technology as trends for employee training.

This brief literature review illustrates the relevance of automation for CT optimization and the neglection of automated TL handling processes in related studies. Scientific studies on CT research often investigate optimization issues in the field of yard, STS cranes or terminal layout by OR models. Only few publications, such as Hinkka et al. (2016), use qualitative methods like case studies for scientific research on container ports.

3. Research method

3.1. Justification and overall design of the study

The literature reviewed in Sect. 2 illustrates a research gap. Some scientific publications deal with the technical problems of TL handling while most OR studies omit the sub-process of TL handling. No study, however, analyzes ATLH-related optimization potentials for CTs, triggers and barriers of ATLH implementation and operation or issues of manual TL handling. Although different systems are briefly examined, a differentiated investigation of the topic is not conducted. Issues connected to the stagnation in ATLH are mentioned in Sect. 2.3., but research remains scarce. Requirements and perspectives of different stakeholders are not included and evaluated in existing literature. Lastly, no study uses a quantitative approach to gather real-world data on speed, throughput or efficiency values related to the employment of ATLH. This research gap justifies the study at hand which aims at (1) identifying prerequisites, triggers and barriers for the implementation of ATLH system solutions as well as related optimization potentials and (2) revealing casual relationships concerning the development and adoption of such technology.

Since the study strives for exploring and generating theoretical background about ATLH systems, case-based research with its explorative character and its ability to test established theory or to generate new theory from observations is the method of choice (Eisenhardt, 1989; Seuring, 2008).[7] This study follows the five stages of case research proposed by Stuart et al. (2002) and displayed in Fig. 3. The case study research process can be divided into five stages of (1) formulating the research question, (2) instrument development, (3) data gathering, (4) data analysis and (5) dissemination.

Data and information are gathered by exploratory expert interviews which represent a suitable approach to “gain knowledge and orientation in unknown or hardly known fields” (Döringer, 2020, p. 3, Bogner and Menz, 2009). Semi-structured interviews are conducted with experts from multiple firms and stakeholder groups who are involved in the automation process of TL handling. These organizations in turn represent the unit of analysis in this multiple-case study research design. Stakeholders such as ATLH suppliers, TL manufacturers, terminal operators, OHS associations or shipping lines are derived from scientific literature and observation during the data gathering. The experts were deliberately chosen from different areas of the broad field of container logistics to reflect the required process integration over the whole maritime logistics chain. When selecting the experts for the interviews, we followed Gläser and Laudel (2009b, p. 117) who “define ‘experts’ as people who possess special knowledge of a social phenomenon which the interviewer is interested in” and Meuser and Nagel (1991) who define “experts (…) as persons who are responsible for the development, implementation, or control of a solution” (Döringer, 2020, p. 2). Homogeneity of the expert group results from the

[7] Due to the limited number of implemented ATLH systems, a quantitative approach would result in poor data gathering.

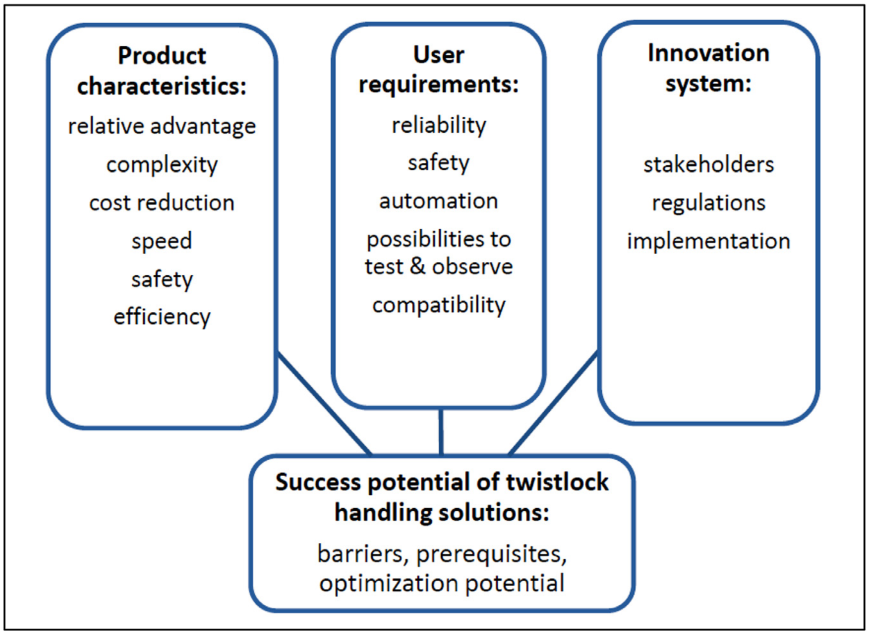

Fig. 4. Innovation framework (adapted from Wiegmans and Geerlings, 2010, p. 237).

circumstance that all interviewees possess a high level of expertise as indicated by the experts' job experience and the segment of maritime logistics in which their firms make business.

3.2. An innovation framework as a fundament

To facilitate a structured scientific approach to the unexplored field of ATLH, an innovation framework developed by Wiegmans and Geerlings (2010) is adapted to conceptualize the success potential of port innovations. It serves as the theoretical basis for both the research question and the interview guide. Further use of this framework is made during data analysis when categories for the qualitative content analysis of the conducted interviews are defined. As illustrated in Fig. 4, the framework consists of three major dimensions: (1) product characteristics, (2) user requirements and (3) innovation system.

Product characteristics describe attributes of TL automation solutions in the perceiver's reception (Rogers, 2003), e.g. complexity as the degree to which TL automation solutions are perceived as more sophisticated or require higher qualification and training than manual TL handling. If ATLH-solutions shall be implemented, it is important that they better meet user requirements, i.e. needs of terminal operators regarding factors such as reliability, costs, safety or speed (Wiegmans and Geerlings, 2010). An ATLH innovation system comprises (competitive) forces – involved stakeholders, regulations or the implementation strategy – which interact with an innovation (Wiegmans and Geerlings, 2010; Priemus and van Wee, 2013). For example, new regulations may demand improvements in OHS and, thus, drive automation implementations.

3.3. Executing the research process

The study at hand examines the widely unexplored field of ATLH in modern CTs. An overarching research question is formulated to illuminate casual relationships and key aspects:

What are potential prerequisites, barriers and optimization potentials for the automation of the twistlock handling process in container terminals?

From this overarching question, four more differentiated and detailed sub-questions are derived:

1 How widely adapted is ATLH in container terminals and what are its barriers?
2 What are user requirements towards automation of the TL handling process?
3 What are economic effects and other impacts of TL handling automation?
4 How should ATLH technology be implemented in container terminals?

Sub-question (1) was developed inductively by own considerations. Questions (2), (3) and (4) are derived deductively from the innovation framework described in subsect. 3.2.

These questions are elaborated on by semi-structured expert interviews that help gaining access to profound expertise and in-depth understanding of complex issues. An interview guide as appropriate instrument enables flexibility in sequence and formulation of the questions and allows placing additional questions that arise during the interview. Specific direct and indirect ques-

Table 1
Conducted interviews.

Organization*	ID	Job experience in this industry	Position	Interview duration (mm:ss)
ATLH provider 1 [(a)]	S1	12 yrs	CEO	35:15
Consulting agency 1 [(b)]	C1	35+ yrs	Agency owner	16:48
Consulting agency 2 [(c)]	C2	10 yrs	CEO and lecturer	24:12
Consulting agency 3 [(c)]	C3a	10+ yrs	Head of Engineering	34:57
	C3b	3 yrs	Consultant	
CT operator 1 [(c)]	T1a	30+ yrs	Team leader quayside operations	42:42
	T1b	30+ yrs	OHS supervisor	
CT operator 2 [(c)]	T2	15+ yrs	COO	27:50

* Due to confidentiality, all information on the interviewees and the firms is anonymized.
(a) Germany, Baltic Sea
(b) USA, West coast
(c) Germany, North Sea

tions for key issues and additional upholding questions are formulated in advance. The interview guide comprises an introduction of the interviewer, a note about confidentiality, an introduction of the interviewee and four main topics. To check comprehensibility and logic, the questionnaire (see Appendix 1) is pre-tested in test interviews conducted with students under real-world conditions.

For data gathering, interviews with an expected duration of 30 to 45 minutes are conducted and recorded to allow precise transcription and to draw the attention to the interview itself. Experts in the sense of this study are managers, engineers, consultants and other practitioners as well as researchers with specialized knowledge or experience in the background of CTs or terminal automation. Interviewees were identified through reviewed literature and online search for ATLH providers and ATLH-related patents. The interviewee group was further extended by the snowball technique, i.e. by asking interview partners for further potential interview partners. First contact was established by email with a partly standardized cover letter. Contacts from Europe and Germany were slightly favorized, as these would allow for a personal meeting instead of using telecommunications.

For each stakeholder group, up to 15 contacts were gathered and contacted. In total, 34 organizations or experts were contacted out of which 12 responded. This results in a response rate of 35.3 %. Eight experts from six organizations as listed in Table 1 have been interviewed resulting in three hours of recorded audio files and 38 transcription pages. In two interviews (C3 and T1), two experts were interviewed simultaneously and not independently and thus jointly made their statements.

The interviewed experts are members of one ATLH provider, three consulting firms for maritime logistics and port operations and two CT operators. Maritime logistics and container handling represent core competences of each of these firms. Hence, the group of experts covers a broad range of SC actors who are involved in the related field of research, i.e. port operations in general as well as maritime container logistics in particular. The group of experts bundles competences that are required for a comprehensive judgment of the process and the underlying technology of TL handling. These competences range from commercial expertise and upper management experience over technical knowledge and process know-how to knowledge about CT operations in general and experience in TL handling in particular.

Each expert has several years of relevant job experience, on average 18+ years, in maritime logistics and container operations and thus is considered eligible for giving informed answers in the interviews. Each expert confirmed to possess sufficient knowledge and experience to inform about the characteristics of the ATLH solution and to judge its advantages, prerequisites, benefits and limitations. Each interviewed expert has knowledge about different TL systems and has experienced such systems in operation.

The number of available experts is limited by the circumstance that the study focuses on a specific and detailed aspect of container operations. However, being based on information provided by eight interviewees from six firms, our study is in line with the common and suitable number of cases (Eisenhardt, 1989) and numerous earlier empirical studies in which comparably few interviews were conducted with a similar number of experts (e. g. Oelze et al., 2020, with five interviewees; Wolf and Seuring, 2010, with nine interviews; Hannibal and Kauppi, 2019, or Warasthe et al., 2020, with ten interviewees; Brömer et al., 2019, with 13 interviewees).

As suggested by Gläser and Laudel (2009a), qualitative-quantitative content analysis is applied for data analysis to evaluate the transcribed expert interviews. Content analysis "is a research technique for the objective, systematic and quantitative description of the manifest content of communication" (Berelson, 1952, p. 55) "that can be applied both in a quantitative and a qualitative way" (Seuring and Gold, 2012, p. 546).

The software MAXQDA is used for transcription as it facilitates a slightly faster, yet manual transcription of recordings and an effective coding of the data. The applied transcription rules are listed in the appendix of this manuscript. For the quantitative content analysis, counts of textual units in terms of coding categories are evaluated (Krippendorff, 2013). The coding categories are developed in a mixed approach as suggested by Seuring and Gold (2012). Analytical categories are deductively derived from the framework introduced in Subsect. 3.2. and complemented by further analytical categories developed inductively during the coding process. As listed in Table 2, in total 36 categories grouped into four structural dimensions are used for data analysis.

Table 2
Structural dimensions and analytical categories for the coding of the expert interviews.

Structural dimension / analytical category *	Deduced from framework	Induced during interview
Perceived product characteristic		
Turnaround time		x
Emerging costs		x
Cost reduction / labor savings	x	
Missing link		x
Complexity	x	
Relative advantage	x	
Cargo handling speed	x	
Safety	x	
Efficiency	x	
User requirements		
Reputation		x
Compatibility & integration	x	
Performance		x
Environmental issues		x
Reliability	x	
Possibility to test & observe	x	
Safety	x	
Innovation system		
Diffusion	x	
Other automated system		x
Job loss		x
TL standardization		x
Vessel type		x
Cooperation		x
Shipping lines	x	
Implementation	x	
Trade unions	x	
Conflicts	x	
Labor costs		
TL system types		x
TL system 1		x
TL system 2		x
TL system 3		x
Manual handling		x

*Structural dimensions are underlined and in italics.

For the within-case analysis, each categorized statement of an interviewee is summarized in MAXQDA to condense different attitudes of interviewees regarding analytical categories. Each interviewee's attitude towards each analytical category is derived from these summaries and noted in the table with a key letter that defines how a category affects ATLH according to the expert's opinion. The overall frequency of named categories is extracted from the interview transcripts. Although the main focus remains on the qualitative approach, the quantitative analysis acts as an indication for ranking the importance of analytical categories and serves the comprehensive presentation of results. The quantitative indication is then linked to the qualitative data that is extracted from the interview transcripts. This combined qualitative-quantitative content analysis follows Krippendorff (2013). Intersections as well as discrepancies between quantitative and qualitative content analysis are outlined in the results, allowing to draw more insightful conclusions.

To disseminate general findings obtained from the study, the conceptual framework introduced in subsect. 3.2. is refined according to the research results obtained from the expert interviews of the case study. The revised framework fits the specific application context of ATLH and shall provide guidance in this automation domain to practitioners and researchers.

3.4. Scientific rigor

This study fulfills aspects of scientific rigor in case-based research (Rowley, 2002; Seuring, 2008). Construct validity is ensured by applying a conceptual framework as theoretical foundation and by using predefined terms and multiple sources of evidence with interview data triangulated by calculations. Pre-testing the questionnaire and using an innovation framework to link findings to conditions ensures internal validity. External validity is obtained by involving multiple interviewees in different positions from various stakeholder groups in a systematic approach. Reliability is achieved by using a standardized interview guide, recording and protocolling interviews and transcribing them according to clear rules and evaluating them based on consistent and pre-defined coding schemes. Theoretical saturation is achieved in this study although the number of conducted interviews is not very high.

Table 3
Overall observed frequencies per analytic category.

Analytical category	Frequency		Analytical category	Frequency	
	abs.	rel.		abs.	rel.
diffusion	23	6.9%	efficiency	9	2.7%
safety	21	6.3%	TL system 2	9	2.7%
implementation	20	6.0%	trade unions	8	2.4%
TL standardization	19	5.7%	performance	8	2.4%
TL system 1	18	5.4%	cost reduction	7	2.1%
reliability	18	5.4%	job loss	7	2.1%
labor savings	15	4.5%	missing link	6	1.8%
complexity	15	4.5%	turnaround time	5	1.5%
conflicts	15	4.5%	shipping lines	5	1.5%
emerging costs	12	3.6%	vessel type	5	1.5%
possibility to test & observe	12	3.6%	environmental issues	3	0.3%
cooperation	12	3.6%	relative advantage	3	0.3%
cargo handling speed	12	3.6%	labor cost	3	0.3%
compatibility & integration	12	3.6%	reputation	2	0.6%
TL system 3	10	3.0%			
other automated systems	10	3.0%	**TOTAL**	**333**	**100.0%**
manual handling	9	2.7%	*Average*	*10.7*	*3.2%*

Table 4
Interview results for the perceived product characteristics

Analytical category	Expert interview S1	T1	T2	C1	C2	C3	Remark
Missing link	P	-	P	P	P	-	
Safety	P	P	P	P	P	P	
Cost reduction / labor savings	P	P	P	P	P	P	
Efficiency	P	P	X	P	P	X/P	
Relative advantage	-	-	P	P	P	-	
Complexity	N	N	N	P	P	P	P = incr. complexity N = similar complexity
Cargo handling speed	P	P	X	-	P	X	
Turnaround time	-	P	X	P	P	-	
Emerging costs	-	N	N	N	X	N	P = low cost incurred N = high cost incurred

4. Results

4.1. Interview results

4.1.1. Overall observed frequencies

A total number of 333 interview passages are coded by analytical categories and result in between 48 and 69 coded segments used per interview. Table 3 lists the total frequency of each analytical category code in the interview transcripts and illustrates the perceived prevalence of the interviewees.

Diffusion, safety and implementation represent the most often used categories while reputation and environmental issues only play minor roles. Passages coded according to the different available TL systems indicate their diffusion and reputation not only among the interviewees in particular but also within the maritime container logistics sector in general.

For each of the four structural dimensions, the analytic categories and the corresponding interviewees' attitudes are condensed and visualized by the following keys and complemented by verbal remarks:

- P ⇔ analytical category is positively affected by automation of TL handling
- N ⇔ analytical category is negatively affected by automation of TL handling
- X ⇔ analytical category is not affected by the automation of TL handling
- - ⇔ analytical category is not named by interviewee

If two experts participated in one interview (T1, C3), their data is counted as a single expert opinion.

4.1.2. Structural dimension "Product characteristics"

For the perceived product characteristics, Table 4 lists the number of interview transcripts in which a certain analytical category is used to mark an interview segment.

Four experts (S1, T2, C1, C2) see automation of the TL handling process as the *missing link* in CT automation and regard TL handling by dock workers as the last remaining unautomated task at CTs.

Table 5
Interview results for perceived user requirements.

Analytical category	Expert interview						Remark
	S1	T1	T2	C1	C2	C3	
Reliability	P	P	P	P	P	P	P = important
Performance	P	P	P	P	P	P	N = not important
Possibility to test & observe	P	P	P	P	P	P	
Safety	-	P	P	-	-	P	
Environmental issues	P	-	-	-	-	-	
Compatibility & integration	P/N	N	N	-	N	P/N	P = crane integration N = standalone system
Reputation	-	-	-	N	N	-	

Automated TL handling is seen as having positive impacts on process *cost reduction and labor savings*, on *safety* and on *efficiency*. All experts agree that ATLH solutions improve *safety*, mainly by removing humans from the hazardous working area. However, manual TL handling on an elevated lashing platform is already very safe and safety in the automated handling process can only be ensured if TL handling plants are guaranteed not to fail and operate at very high reliability (C3). The experts emphasize safety requirements also for a combined operation of automated and manual TL handling.

All respondents assess ATLH solutions to result in *cost reductions* induced by labor savings from the substitution of manual labor through automatic processes. Significant cost reductions are presumed (C1) and anticipated labor savings are estimated to account for one to three dock workers per shift and STS crane (T1, S1). Importantly, the opportunity to substitute manual labor is regarded as a prerequisite for deploying automation.

Positive *efficiency* impacts leading to better utilization of labor and equipment are predicted by four experts (S1, T1, C1, C2). Reliability of ATLH solutions (C1) and long-term deployment of the automation technology (T1) represent prerequisites for efficiency gains. Thorough operational planning of TL logistics can lead to further efficiency improvements (C2). However, two experts expect equal efficiency of automated and manual handling (T2) or anticipate only minor efficiency gains (C3).

The interviewees have ambiguous judgments on the *relative advantage* of ATLH systems. Only three experts (T2, C1, C2) see positive impacts on a CT if such a technology is employed. This is mainly due to heterogeneous opinions about the complexity of the automated solution and its impact on cargo handling speed and turnaround time. Regarding the *complexity*, the extent of required maintenance and dock workers training is difficult to estimate (C1). Due to higher qualification requirements former lashers may be left behind and will not necessarily remain future operators of automated TL handling solutions (C2). The technical property of a particular system solution may further add complexity (T1).

Only three experts (S1, T1, C2) expect ATLH solutions to deliver higher *cargo handling speed*. This will mainly result from eliminated manual lashing times at STS cranes. Furthermore, dock workers assigned to manual TL handling suffer from fatigue thereby slowing down the handling process (T1). Achieved speed improvements depend on the position of the TL handling plant and the possible number of moves per hour that a system can perform (S1). Two other experts (T2, C3) consider ATLH only to be a substitution of the handling process itself and therefore lead to equal cargo handling speed. Since ATLH must not be slower compared to manual handling, cargo handling speed represents a product characteristic and simultaneously a user requirement. Four experts consider effects of ATLH on ship *turnaround time*, three of them (T1, C1, C2) predicting shortening turnaround times and one interviewee (T2) expecting no change in comparison to manual TL handling, because only the process below the STS crane is altered but nothing else.

Emerging costs for maintenance or disturbances in operation are expected by four experts (T1, T2, C1, C3). High investment requirements are also anticipated for a physical integration of ATLH solutions into existing STS cranes, because every crane would require its own ATLH system and complex installation (T1, T2, C3). However, costs represent the largest perceived product-related barrier for the adaptation of ATLH systems.

4.1.3. Structural dimension "User requirements"

The summarized insights on perceived user requirements gained by the interviews are listed in Table 5.

Reliability, performance and *possibility to test & observe* are marked in every interview transcript. ATLH solutions are required to handle a variety of different types and shapes of TLs with sufficient *reliability* (C1, C2, C3, T2). The systems must be failsafe (C3) and definitely must not interrupt crane operations (C1, C2, T1, T2, S1). Reliability represents a crucial point for successful implementation (T2, C2). Maintenance or downtime due to a lack of reliability would constitute a major disadvantage of ATLH (T1). Resulting from the reliability necessity, all experts agree that the *possibilities to test and observe* ATLH solutions in operation are a key requirement. The possibility to examine reference plants, possibly at a manufacturer's site, is important, but hardly any terminal is eager to be the first one in testing such technology (C1, C2, S1). Terminals will only be willing to serve as test partners if resources and time are available, but not if productivity and uninterrupted operation have priority (T2).

Issues regarding the *performance* are related to susceptibility to faults as TLs may get stuck (T2) and to the independence from external power supply, such as electric cables that would cause inflexibility and obstruct the yard area and in addition may lead to accidents with yard vehicles (T1, T2). The inability to handle the variety of TLs and external power supply problems of certain ATLH solutions are seen as major barriers (C2, T1, T2). Storage and transport of TLs represent other important performance and differentiation criteria (S1).

Table 6
Interview results for perceived user requirements.

Analytical category	Expert interview S1	T1	T2	C1	C2	C3	Remark
Diffusion	X	N	X	X	X	X	N = minor diffusion X = no diffusion
Other automated systems	P	-	P	-	P	P	P = other automation technology advances
Type of vessel or ship	N	-	N	N	-	-	N = not suitable for all vessel types
TL standardization	N	P	N	N	N	-	various TL types cause… P = …minor issues N = …major issues
Role of shipping lines	-	N	N	X	X	X	N = lines not involved X = other, see main text
Cooperation	P	-	P	P	P	P	P = cooperation required
Noticeable conflicts	N	X	P	P	P	N	P = minor conflicts N = major conflicts X = no conflicts
Trade unions	N	P	P	N	N	N/X	P = unions DO NOT cause issues N = unions DO cause issues X = unions cooperate
Workforce reduction	P	P	P	P	P	N	P = not an issue N = is an issue
Labor cost	-	P	P	P	-	P	P = large impact

Although important, safety and environmental issues are less often addressed. As explained above, *safety* is seen not only as a product characteristic, but also as a user requirement (C3, T1, T2). Safety requirements concern the maintenance of ATLH systems (T1b) as well as its simultaneous operation with manual handling (T2). In cases of multiple accidents related to TL handling, OHS authorities may demand better automation for enhanced safety (T2). The consideration of ecologic safety and *environmental issues*, such as oil pollution, emissions and type of power supply is named by one expert (S1). No other expert addressed green technology issues in context to ATLH.

Compatibility & integration addresses the possibility to either integrate ATLH solutions into STS cranes or use standalone solutions, which operate independently from other equipment. Integrating the ATLH system into the STS crane is the most sophisticated solution but is associated with high investment requirements and cost due to complex installation which in turn makes a standalone solution cost-efficient (C3, T1). Standalone systems allow the exchange of plants in case of failures and consequently avoid interruptive impacts on the STS crane (T2, C2). Standalone solutions are rather suitable for terminals using straddle carriers, whereas an integration into the cranes is preferred for AGV or truck terminals (S1, T2).

Reputation is named by two experts (C1, C2) in context to disturbances in loading and unloading operations and resulting negative impacts on the terminal's reputation due to failed ATLH implementations in the past.

4.1.4. Structural dimension "Innovation system"

The summarized insights on the innovation system gained by the interviews are listed in Table 6.

Aspects of worldwide technology *diffusion* – either nowadays or in future – are addressed in every interview. All interviewees agree that ATLH is currently not fully operational in any CT and that manual handling is maintained as the primary method. However, half of the experts (S1, C1, C2) are convinced that ATLH will spread globally over the next 5-10 years while the other half (T1, T2, C3) predict ATLH technology not to diffuse in the near future.

Other automated systems for advancing CT technology are mentioned in four of six interviews (S1, C2, C3, T2). Examples for such systems include remote controlled twistlocks which can be remotely locked and unlocked between container layers, test phases of autonomous driver-less SCs (S1, T2) or autonomous or remotely controlled STS cranes (C2). Some interviewees expect that such other automated systems have similar or deeper impacts on CTs than ATLH (S1, T2, C3).

Arguments concerning the *type of vessel or container ship* are raised by three experts (S1, T2, C1) who explain that ATLH solutions are hardly suitable for small feeder ships and barges due to poor efficiency gains for small vessels. In contrast, newly built ultra-large container ships are not expected to cause any problem in ATLH adoption (T2) due to new and mostly uniform TL sets on board.

Most experts expect that *TL standardization* causes minor (T1) or major issues (S1, T2, C1, C2) while only one expert (T1) does not see any issues arising from large variety of TL types. Ships need to keep a mostly uniform TL set without a mixing of different variants (S1). Hence, global standardization of TLs with harmonization of different types and shapes would present a major advantage for TL handling in general (C1, C2, T2). Standardization is seen as a prerequisite for the diffusion of ATLH in general (C2), but it can only be achieved if all shipping lines cooperate in the circulation of TLs between vessels and terminals (C3).

The *role of shipping lines* in the innovation system is addressed by five experts (C1, C2, C3, T1, T2). When shipping lines need to invest into renewal of TL sets onboard of ships, standardization considerations should be enabled (C1, C2, C3). One interviewee (T1) assumes that the lines will hardly invest into automation and modernization, such as ATLH, and suggests that shipping lines carry ATLH systems on board of their ships thereby being able to operate independently from the port and with higher efficiency in terms of TL handling.

Table 7
Interview results for perceived user requirements.

Analytical category	Expert interview						Remark
	S1	T1	T2	C1	C2	C3	
TL system 1	O	O	O	K	O	K	
TL system 2	K	K	K	K	K	U	
TL system 3	K	K	U	U	K	U	
other TL system	-	O	-	-	-	K	T1 = system observed in Rotterdam C3 = remotely controlled twistlock

O = TL system observed in operation, K = TL system known by expert, U = TL system unknown, - = not mentioned

Five experts (C1, C2, C3, S1, T2) consider *cooperation* between stakeholders an important factor of innovation. ATLH suppliers need to cooperate with terminal operators to gain reputation and to showcase the system thereby enabling the required market diffusion (C3). Moreover, cooperation is required between shipping lines and terminal operators in terms of TL standardization (C1, C2, T2). Furthermore, cooperation between terminal operators and lashing service providers (S1) and with trade unions and legal authorities (C3) may mitigate possible conflicts and prevent from reluctance to change. In the end, all stakeholders must support ATLH implementations in order to be successful (S1). Cooperation is required to optimally integrate the technology and to avoid operational disturbances while a lack of cooperation would represent a major barrier of ATLH (S1).

Minor (S1, C3) or major *conflicts* (T2, C1, C2) are addressed in all but one interviews while only one expert does not expect any conflict (T1). Conflicts may arise from tensions between operators and trade unions (S1, C3) or from the dock workers' reluctance to adapt to the new technology (S1). However, even larger conflicts are expected to be resolvable (T2, C1, C2).

Trade unions embody a much versatile role in the innovation system according to all experts who all expect that unions react negatively towards automation attempts. Reasons for the assumed negative attitude of trade unions include expected job losses (S1) and labor savings (C3) and the associated general reluctance to automation projects (C1, C2). However, all experts see possibilities that the argument of occupational safety and health improvements may overmatch apprehension of workforce redundancies and job cuts. All interviewees propose involving trade unions at the early stage of an automation project. Once convinced, trade unions may also add beneficial ideas to these projects.

Although automation in general often leads to a *reduction of the workforce*, five experts (S1, T1, T2, C1, C2) do not see the substitution of dock workers as an important issue. Former lashers will either carry out other tasks which they have originally been trained for (T2) or they will evolve into higher qualified workers that operate ATLH systems (T1). In general, the amount of required labor in terminals is expected to increase (T1) and moreover, job loss will not present an issue for greenfield projects (C3). However, some lashers who will not be able to carry out higher qualified tasks may therefore be left behind (C2) and conflicts with the workforce and subcontracted lashing service providers may arise (C3). Despite of this, the vast safety improvements imposed by ATLH may easily outperform the substitution of dock workers (C2).

Four interviewees (C1, C3, T1, T2) expect that national *labor costs* play an important role in the adaptation of ATLH systems. Due to limited savings potential, countries with low labor cost will lag to employ automation solutions while the opposite may be valid for countries with high labor costs (C1, C3, T1). Rising labor costs with stagnating profits may drive automation and substitution of manual labor (T2), but low labor cost levels may turn out to be a barrier for ATLH investments because of extraordinary long payback periods (T1).

Expert opinions about crucial factors for successful ATLH *implementation* differ widely.[8] Important factors include the capability to handle diverse TL types (C1, T2) and the system reliability (C2, C3, T1, S1) as well as the availability of time and resources (T1, T2, C1). One expert (C2) emphasizes the importance of internal TL logistics and pre-planning in order to provide the right number of TLs at the right handling plant at the right time. Four experts (S1, T1, T2, C3) inform about possible roll-out strategies for implementation. All experts agree that test implementations on few STS cranes are vital before equipping the whole terminal, and one even proposes a roll-out strategy that only covers test phases but no full implementation (C3). An implementation should be conducted successively in different phases thereby increasing the number of STS cranes equipped with ATLH over time (T1, T2, S1). However, not all cranes must necessarily be refitted with ATLH, because some may remain with manual handling for feeder ships and smaller vessels (S1, T2). This approach may enable the use of a smaller, flexible number of standalone ATLH-solutions instead of a terminal-wide crane integration.

4.1.5. Structural dimension "TL system types"

Insight on the popularity of different TL systems as observed from the interviews is summarized and compared in Table 7. Detailed information on the systems and their providers remains undisclosed to respect non-disclosure agreements and to prevent from surreptitious advertising.

TL systems 1 and 2 are best-known ATLH solutions. TL system 1 is familiar to all experts and was already observed in operation by four of them. Only one expert has not heard of TL system 2, but no expert has seen this system in operation. TL system 3 is less

[8] Factors and roll-out strategies are summarized and compared in Table 8 in the appendix of this paper.

Table 8
Summary of implementation strategies and crucial factors.

Interviewee	Crucial success factors for implementation / Roll-out strategy (if named)
C1	- performance: capability of ATLH-solution to handle various TL types - standardization of TLs in cooperation with shipping lines - economic environment: time and resources availability
C2	- reliability - system's independence from STS crane / exchangeability - internal TL-logistic/TL-supply for ATLH-systems; pre-planning
C3	- reliability - possibility to test and observe - technical certification and regulatory approval from authorities - early involvement of trade unions *Roll-out strategy:* *1) establish cooperation between supplier, terminal operator and trade unions* *2) develop prototype/establish field experiment in container terminal; obtain certification* *3) proof of technical and economic advantages* *4) provide possibility to observe for other terminals*
T1	- inclusion of OHS authorities - pre-test of reliability - economic environment: time and resource availability *Roll-out strategy:* *1) pre-test of reliability at few and smaller berths (for feeder ships)* *2) upscaling on other berths/larger STS cranes according to test results* *3) use integrated solutions only where necessary*
T2	- internal communication of job transition to workforce - training and qualification of workers for ATLH - performance: capability of ATLH-solution to handle various TL types - possibility to transport ATLH system with terminal vehicles (SCs, AGVs etc.) - economic environment: time and resource availability *Roll-out strategy:* *1) participate in test phase and development, if resources allow* *2) estimate peak-usage of STS cranes in terminal (not all cranes are used simultaneously)* *3) purchase standalone ATLH-solution for peak usage e.g. 14 of 18 STS cranes* *4) deploy ATLH-solution in stages/successively*
S1	- reliability - acceptance of technology by workforce - integration into terminal operating system/communication with other equipment - uniform TL sets onboard ships - planning of workforce reduction under social aspects - cooperation between all stakeholders *Roll-out strategy:* *1) deploy ATLH in stages for half (50 %) of STS cranes* *2) expand ATLH for 2/3 of STS cranes* *3) expand ATLH for all STS cranes, except one used for handling barges and feeder ships*

popular and unknown to every second expert. One expert (T1) has seen a different system in operation in the port of Rotterdam and one other expert (C3) has worked with a remote container locking system with remotely controlled TLs.

4.2. Refined conceptual framework

The innovation framework adapted from Wiegmans and Geerlings (2010) as introduced in Subsect. 3.2 is refined according to the research results obtained from the conducted expert interviews. It is revised to match the specifics of ATLH technology. By ranking the relevance of displayed attributes, the conceptual framework shall provide guidance to researchers and practitioners in this automation domain. In addition, the framework may also be used to assess the success potential of other port innovations.

The attributes of the refined framework depicted in Fig. 5 are compiled from the basic framework and from analytical categories developed during data analysis. Product characteristics are expanded for ATLH by *missing link, training requirements* and *emerging costs. Speed* and *efficiency* were consolidated into possible, yet not guaranteed *efficiency improvements*. User requirements are expanded by *integration. Performance* is added, which means most importantly TL handling capability and independent power supply. The importance of *possibilities to test & observe* is emphasized. The innovation system now contains the most important stakeholders while less important stakeholders such as OHS associations, consulting agencies or shipping lines are not explicitly mentioned in the framework but could be added if required. Important factors consist of the identified prerequisites for ATLH adaptation and implementation. The success of ATLH implementation is determined by prerequisites, barriers and optimization potential.

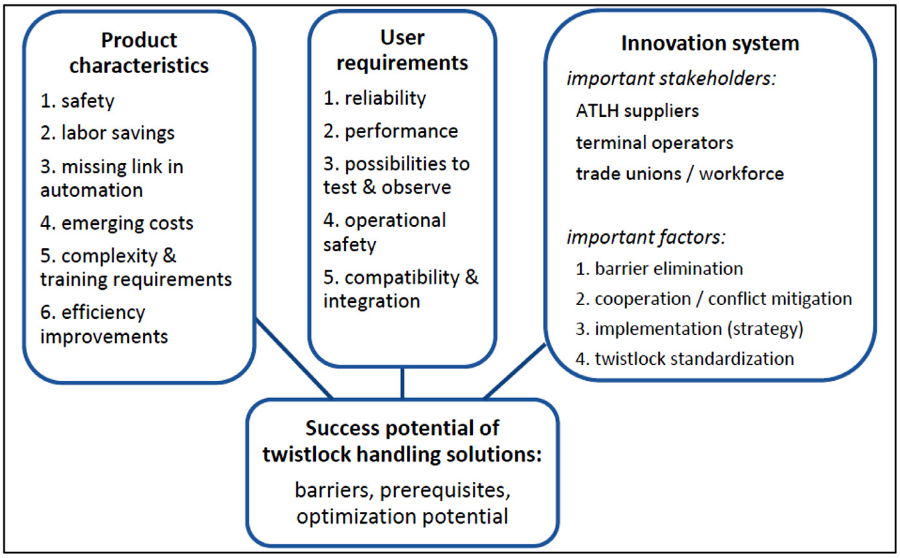

Fig. 5. Revised conceptual framework for automated twistlock handling.

5. Conclusion

5.1. Findings

RQ1: How widely adapted is ATLH in container terminals and what are its barriers?

With regard to RQ1, the study has shown that the diffusion and adoption of ATLH is extremely low, apart from some reported test implementations on which there is no information available.

In total, nine main barriers for ATLH adaptation in CTs were identified. Mostly technical barriers include (1) reliability, (2) the inability of ATLH solutions to reliably handle a variety of TL types, (3) industry-wide standardization of TLs and (4) external power supply. From an economic perspective, (5) national labor costs and investment requirements for automation are presumed to be potential barriers but need further examination. Regarding collaboration, (6) conflicts with trade unions are presumed to impede ATLH as well as (7) missing cooperation along stakeholders are considerable barriers, which have been observed in the past. Regarding market diffusion, (8) negative reputation due to failed implementations and (9) missing possibilities to test and observe represent major impediments.

RQ2: What are user requirements towards automation of the TL handling process?

To answer RQ2, four key factors are identified as user requirements towards ATLH. Firstly, (1) solutions must operate at highest possible reliability to avoid unplanned interruptions in the terminal. Secondly, (2) high performance standards in handling various TL types and worn-out TLs must be achieved. Moreover, independence from external power supplies is essential. Thirdly, (3) ATLH solutions need to operate safely, also for combined manual and automated usage as well as their maintenance. (4) Users of ATLH require possibilities to test and observe in order to obtain evidence of the above factors and to build up reputation. Additionally, standalone and integrated solutions should be both available, though standalone solutions being the preferred version.

RQ3: What are economic effects and other impacts of TL handling automation?

To answer RQ3, the following six major impacts and economic effects have been identified which are associated with the deployment of ATLH in CTs: (1) Fundamental safety improvements and riskelimination for workers, (2) cost reduction and labor savings through substitution of dock workers, (3) elimination of manual TL handling as the weakest link, (4) increased complexity and training requirements for dock workers and (5) significant emerging costs for investment, maintenance, training and integration of ATLH. Impacts on terminal efficiency, cargo handling speed and ship turnaround times are possible, thus not guaranteed. (6) Improvements in labor utilization are promising. Impacts in terms of job loss and emergence of labor conflicts are similarly controversial and lack reliable data.

RQ4: How should TL handling technology be implemented in container terminals?

To answer RQ4, an implementation strategy has been refined and summarized from obtained data. The deployment of ATLH in CTs should be conducted successively in stages, starting with test implementations on few STS cranes. After testing, ATLH is further equipped at other STS cranes with a certain number of cranes remaining to employ manual TL handling as an emergency solution for vessels difficult to handle. Establishing test implementations is crucial, as it presents the starting point for a terminal-wide deployment and provides evidence of automation advantages. Every CT, however, is unique and therefore requires an individual and tailor-made strategy that fits to its specific requirements. Eliminating barriers and fulfilling user requirements needs to be achieved in advance of test implementation. Moreover, cooperation between ATLH suppliers, terminal operators and trade unions is crucial for successful implementation and operation of the ATLH system and its acceptance.

5.2. Managerial implications

The study strongly recommends that ATLH suppliers establish possibilities to test and observe. Resolving performance and reliability issues are the top priorities. Terminal operators need to be open for cooperation, better actively allocate resources to promote ATLH developments and may want to make due considerations of labor savings.

A supply chain-based view on the automation chain is mandatory to generate and exploit benefits of ATLH and to share them between all involved partners and stakeholders. Cooperation along the transport chain is needed in terms of TL standardization to fully exploit the cost reduction potential and to leverage operational advantages. All relevant stakeholders should abandon any isolated perspective or functional view and strive for process orientation and cooperation to achieve the best possible benefits from this specific port automation.

The study elaborates on ATLH systems and, thus, seems to be narrowly focused on a technical detail. However, considerable efficiency improvements can be achieved across the maritime supply chain by the implementation of such a technical solution. The following arguments explain this in greater detail.

A swift and even material flow is crucial for supply chain performance (Schmenner and Swink, 1998). Since containers can become available faster when using ATLH systems, such technical solutions can improve the fluidity of the entire maritime transport chain which in turn is important to carriers, ports and shippers (Talley and Ng, 2013). Minimizing container dwell times, i.e. the times containers spend in a terminal's yard, helps operating marine terminals at optimum capacity (NgTalley, 2020). For this purpose, robotic technology needs to replace the stevedores' heavy work, because automation improves planning security and safety at work and fully automated processes help gaining efficiency in container handling (Ma et al., 2014b).

CT operators increasingly recognize (on-dock) rail as a complementary mode of container transportation (Ng and Talley, 2020). In the U.S. but also in Australia, Canada, China, India and Panama, double stack rail service is available with containers stacked two high on rail cars (Ng and Talley, 2020). Here, ATLH systems can increase the speed of stacking processes thereby mitigating issues of port congestion (Talley and Ng, 2016).

5.3. Limitations and future research perspectives

The study does not go without limitations. The availability of mostly German experts limits the scope of the study and the generalizability of obtained results. Difficulties in interviewee recruitment resulted in a relatively small number of conducted interviews. Unfortunately, some stakeholder groups such as shipping lines or OHS authorities were not available for interviews and, thus, had to be omitted. However, as the number of conducted interviews increased during the study, hardly any new insights were gained from the last interviews which indicates that the point of theoretical saturation has been reached. Since interviewee T1 passed away unexpectedly two days after the interview was conducted, it was not possible to enquire additional information from that person.

The geographical scope of the study is limited by difficulties in worldwide gathering of data from CTs and lacking responses from experts outside Germany. Future research may focus on validating results in other geographic areas and extend the group of interviewed stakeholders to gain insights from unattained perspectives. Recruitment strategies need to be strengthened for better access to experts.

Moreover, most insights are related to expert knowledge from events in the past while current and topical developments are underrepresented in the study. In-depth data from other system providers and real-world implementation projects would have been helpful to validate the obtained findings. A stronger focus on economic effects and impacts on performance indicators would have enriched the conducted study but unfortunately exceeded its scope. Therefore, these prospects are subject to further research.

Methodological limitations arise from omitting inter-coder reliability tests such as Krippendorff's alpha due to limited research resources. Missing additional triangulation of results impairs construct validity but would have exceeded available research capacity and the extent of the study. The derived ATLH framework is fruitful, yet preliminary. It requires validation and might be extended according to further research in this field.

TL handling automation represents an avenue with great potential in CT research. ATLH is a known, yet unexplored field with great challenges and large potential for the future development of CT automation. At what time this future will become present depends on the willingness of terminal operators, suppliers and other stakeholders to start cooperating in such a way that drives test implementations to success and makes them operationally and financially beneficial.

Declaration of Competing Interest

None.

Appendix 1: Interview guide

Introduction of interviewee

- Name? Age? Company Name/Name of institution?
- Which position/function do you hold in the company?
- What is your academic and professional background?
- Which role does your company play in the domain of container terminal automation?

Diffusion of automated twistlock handling systems

- Do you know systems for automation of the Twistlocks handling? If yes, could you tell me which systems do you know and what these are doing?
- In your judgement, how widespread is the “automation of twistlock handling” at container terminals?
  - ○ Attempts or plans of TL handling automation in CTs?
  - ○ Are you aware of any container terminal, which has successfully automated twistlock handling?

User requirements and barriers

- In your judgement, what are the most important requirements that container terminals/ship owners have towards automated twistlock handling solutions, i.e. what expectations do terminal operators have regarding this technology?
  - ○ Cost reduction, safety issues, speed increase, reliability, efficiency increase?
  - ○ Complete automation of transport chain?
  - ○ Requirements met by existing solutions?
- What do you think are possible barriers regarding the implementation?

Product characteristics

- In contrast to the requirements that terminal operators have, what do you think are the actual advantages & disadvantages that twistlock handling automation technology provides or could provide for container terminals?
  - ○ In your opinion, would terminal operators purchase systems without prior reference?
  - ○ Does the complexity of such plants compared to manual twistlock handling plays a role?

Implementation strategies and factors

- In your opinion, how should twistlock automation be implemented at container terminals and which are the crucial elements for success?
  - ○ Important stakeholders, arising conflicts between stakeholders, trade unions, regulatory issues, technical issues?
- How do you evaluate future diffusion of such technology at container terminals?

Appendix 2: Transcription rules

1. Complete transcription word-for-word. Existing dialects are not transcribed. German dialects are translated into standard German as accurate as possible.
2. Language and punctuation are smoothed slightly, approximate to the written language.
3. Noticeable, longer breaks are marked by ellipsis (…).
4. Particularly emphasized terms are indicated by capital letters, e.g. MONday.
5. Consenting or confirming vocalizations of the interviewer are not transcribed (mhh, ahh, etc.).
6. Objections by the person not currently speaking are marked in brackets (Are you sure?).
7. Noticeable utterances that support or clarify the statement (laughing, sighing) are mentioned in brackets.
8. Abbreviation for the interviewer is “I”, for the interviewee the corresponding code (e.g. S1).
9. All information that allows the identification of an interviewee is anonymized. Names are anonymized by XXX. Companies are anonymized by codes (e.g. Supplier Company 1).
10. Each speaker change is made clear by a blank line between the speakers to increase readability.
11. Misspeaking is marked with a * symbol (e.g. Sy System -> *System).
12. Word repetitions are marked with // (e.g. That means, that means -> That means//).
13. If a word cannot be understood from the recording it is marked by a question mark in brackets (?).

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