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Digitalization in Container Terminal Logistics: A Literature Review

Abstract

Many terminals that are located in large ports, such as Port of Rotterdam, Port of Singapore, Port of Hamburg, etc. employ various emerging digital technologies to handle container and information. Some technologies deemed attractive by large ports are: Artificial Intelligence (AI), Cloud Computing, Blockchain and Internet of Things (IoT). The objective of this paper is to review the "state-of-the-art" of scientific literature on digital technologies that facilitate operations management for container terminal logistics. The studies are synthesized in form of a classification matrix and analysis performed. The primary studies consisted of 57 papers, out of the initial pool of over 2100 findings. Over 94% of the publications identified focused on AI; while 29% exploited IoT and Cloud Computing technologies combined. The research on Blockchain within the context of container terminal was nonexistent. Majority of the publications utilized numerical experiments and simulation for validation. A large amount of the scientific literature was dedicated to resource management and scheduling of intra-logistic equipment/vessels or berth or container storage in the yard. Results drawn from the literature survey indicate that various research gaps exist. A discussion and an analysis of review is presented, which could be of benefit for stakeholders of small-medium sized container terminals.

Keywords: *Digitalization, Container Terminal, Artificial Intelligence, Blockchain, Cloud Computing, Internet of Things, Systematic Literature Review.*

1. Introduction

Globalization and the increasing use of containers for shipping has had a dramatic influence on terminal's business model and operational efficiency. Large ports that have busy container terminals, such as Port of Rotterdam, Singapore and Hamburg have redefined the container logistic processes and operations through the adoption of different digital technologies such as Artificial Intelligence, Blockchain (Vincent Campfens and Charles Dekker, 2018), Cloud Computing and Internet of Things (Heilig et al., 2017c) (Carlan et al., 2017). However, there exist many small-medium sized ports which play an important role in regional and national economies (Helminen, 2014). Due to lack of resources and knowledge small and medium sized ports have a challenge in digitizing its processes and workflows, for container and informarion handling, which hampers its growth and operational efficiency.

This study presents a scientific survey which analyzes research done on technologies that aid in digitization of operations and processes of a container terminal. The technologies investigated as part of this research are: Artificial Intelligence, Blockchain, Internet of Thing, and Cloud Computing, the choice of which is supported by trends analysis done by (Heilig et al., 2017c) (Panetta, 2018) (Briggs et al., 2019). To limit the scope of this paper other emerging technologies such as 5G, Augmented Reality, Cyber-Security and etc. are not considered, but reserved for future studies.

The goal of this literature review is to present the state-of-the-art, in terms of chosen digital enablers to assess the utilization and development of these technologies in performing operations at the container terminal. The scope of operations management in this study refers to operations and processes at the terminal that handle digital information to perform container logistics. The topics around shipping liners' routing or issue of distributing empty containers or that refer to operations beyond the gate such as hinterland problems are considered out of the coverage of this analysis. This research provides an overview of digitalization infiltration in the operations management at the container terminal with the help of the classification matrix that synthesis the selected research studies. The descriptions of the papers are then classified into the classification matrix as: operation type, process type, technology type and research type. The study follows a systematic literature review methodology to reduce the selection bias and make the scientific contribution explicit and reproduceable.

The contributions of the paper can be summarized as follows:

- We present the state-of-the-art of the scientific literature present on digitization for container terminal logistic operations.
- The analysis presented is based on an extensive literature review in which a classification matrix is developed for analyzing existing research to understand how

these digitalization enablers facilitate the information and decision management, process workflows and operations for the container terminals.

- We highlight the trends, identify and understand most common technologies researched with respect to the specific container terminal operation and process and, pinpoint the research gaps.

The remainder of the paper is organized as follows; Section 2 introduces the background in relation to the importance of container terminals in the maritime industry and presents the operations and processes that take place. Section 3 describes what is digitization and digitalization in general and within the context of this study. In Section 4, the research method is described. Section 5 and Section 6 present the literary review results, analysis, classification and discussion. In Section 7 we share conclusion and pointers for future work.

2. Background

Approximately, 80 to 90 percent of the international trade depends on shipping (*50 years of Review of Maritime Transport, 1968–2018*). The purpose of shipping, as mentioned in the literature (Branch, 2014) is the transportation of goods from low utility place to a higher one. The goods consist of liquid bulk; dry or main bulks; other dry bulk or breakbulk; container cargo for consumer goods and ro-ro that is 'roll on / roll off'.

2.1 Problem Area

With the increasing cargo shipments every year, the container terminals have had to keep up with the demands. The container terminal is viewed not as a passive point of interface between sea and land transport but is known as the 'nodal point' in the global transport system. This means efficient container terminal logistic operations and processes are a need for every container terminal to maintain the business (Stahlbock and Voß, 2007). Ports such as Antwerp, Rotterdam, and Hamburg are expanding their terminals to accommodate the projected rise in container throughput. Due to rise in speed and volume, the operations of a container terminal require a better regulating systems approach. Research results from AI, Blockchain and IoT could answer some of the container terminal challenges; e.g. increasing the terminal performance without large investments on terminal expansion or procuring new machinery.

Congestion and increasing cargo dwell times is a common scene in many terminals. Government authorities such as customs and health may delay containers from reaching their destinations due to inspections. Terminal operators are trying to reduce or stabilize the cost per TEU (twenty-foot equivalent unit) container handled and thus, maximize profit. Complications arise when various computer systems work together leading to adhoc planning, ill-defined data and poor information. Today, ports are seeking better ways to improve their productivity and offer logistical solutions to port authorities. No longer are ports handling just container, but becoming more of information handlers (Henesey, 2004).

2.1.1 Container Terminal Operations

In viewing a container terminal as a system, the following operation areas exist; Vessel; Berth, Intralogistics, Yard, and Gate. Figure 1 (Henesey, 2006) illustrates the differing circumference for each operation type screening different needs and issues. For a more detailed account of container terminal operations research, c.f. (Stahlbock and Voß, 2007). A description of the operations involved in the movement of containers is given below:

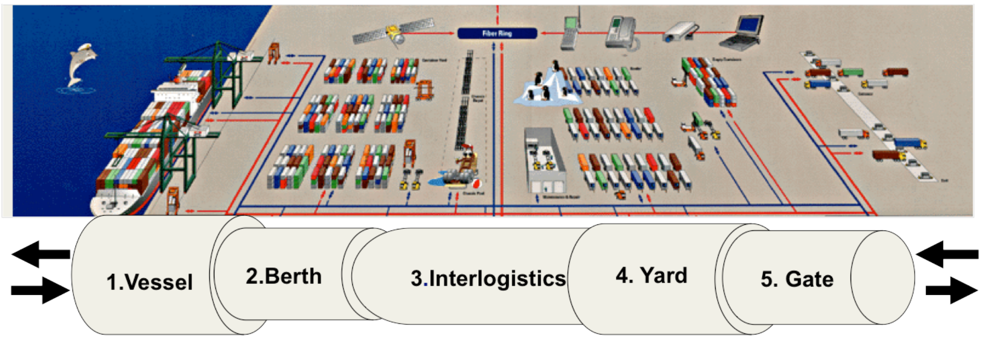

Figure 1 – Operation Types in Container Terminal

Vessel: Synonymously used as the maritime interface where cranes handle vessels. Terminal operators experience problems in reducing the unproductive and expensive container moves. The number of cranes used to perform the operation varies depending on the size of the containership and the volume of containers to be handled. The vessel planning is typically executed 24 hours before a vessel-call by the ship line. The plan includes a manifest, list of containers to be loaded or discharged.

Berth: Each containership that arrives at the terminal will be assigned a berth and a location where a vessel can dock. The characteristics of a container berth are the length, depth, equipment (i.e. cranes), handling capacity, and service facilities.

Intralogistics: Containers are moved from berth to the yard to be stacked or placed in an area for dispatch, or containers from the stack are delivered to the gantry crane at the berth to be loaded on a vessel. The import container information such as its number, weight, seal number, and other information are recorded along with the location identification to a central database, such as a yard system in the terminal. Depending on the operations, either yard tractors, front loaders, or straddle carriers are employed as transport in this operation. The export containers are transferred from a location in a stack, thus notifying a yard system that the location is free and will be given to a gantry crane to be loaded on a vessel.

Yard: There exist three main types of storage systems: short term, long term, and specialized. Specialized storage is reserved for refrigerated, empty, liquid bulk, hazardous materials. The container storage system uses stacking algorithms in assigning a space for the container till it is loaded or dispatched.

Gate: The interface to other modes of transport lies in this system. The managing of the gate is to obtain information of containers coming into the terminal so as to be properly physically handled before ship arrival and to release import containers before the arrival of trucks or rail. Controlling this access to the terminal is important in that it affects other parts of the container terminal system. The data collected for example are; container number, weight, port of destination, IMO number if hazardous, reefer, shipper, ship line, and seal number are used in deciding where to place containers for storage and later for loading.

As part of scope of this research, the problem area is limited to unloading or loading of the container from/to the vessel, to its handling and storage in berth and yard via intra-logistic vehicles such as straddle carriers, cranes, automated vehicles and trucks, and the check-out or check-in that happens at the gate.

2.1.2 Container Terminal Processes

There are different processes that are required in the execution of above operations. The major processes that are important for the efficient handling of containers are the following:

Information exchange: During freight transport verification and validation of the status of the shipments, handover of responsibility, custom documents etc. are exchanged. To execute the allocation, scheduling and management tasks the tools are put in place to allow storing, processing, sharing, visualization and analytics.

Tracking and Tracking: The location and identification of assets is equally important to the location of cargo itself. Improved visibility of assets, such as the equipment to handle the containers and people leads to higher productivity when such information is considered in moving containers.

Sorting and Processing: As a system, the container terminals are constantly sorting incoming and outgoing containers and cargo based on defined criteria and rules. To enable the container terminal management to efficient control the various operations, a number of processing tasks are required that demand expert knowledge and/or the use of computer systems in executing desired decisions.

Resource Management: Various specialized equipment types are used to handle containers. For many operators the objective is the efficient of use of equipment, space, number of workers and other resources in order to minimize costs whilst obtaining high performance.

Scheduling: It is an ongoing process in container port affected by many variables that are often not controllable, such as weather, strikes, congestion or traffic. For instance, the scheduling of arriving containers with vessel calling requires coordination with the schedule of related yard operations and availability of the labor for moving containers.

Integrated processes: Often viewed by container terminal as a “holy-grail” is the decision making that takes into account the multitude of actions and processes to decide on the physical movement of a container by a vehicle from one location to another with minimal costs. Various IT systems are deployed in assisting container terminal management in trying to integrate the processes with the operations.

The described operations and processes often characterize the activities existing in major container terminals. This is possible for different reasons, such as dedicated budget for digitization and digitalization, trained and devoted staff or departments and push from the market or competitors. Hence, making them more competitive than smaller ports. In the distribution of digital technologies for logistics small and medium ports and their service portfolios are argued to be very limited, with no or few processes digitized that are not integrated at the enterprise level and far from cross-border integration. A recent European Union project Connect2SmallPorts[1] generated results that concluded very differing levels and meanings of digitalization in ports, e.g. ports of Wismar - Germany, Karlskrona - Sweden and Klaipeda- Lithuania. Most of the small and medium ports still pursue the classical infrastructural path without any clear vision and digitalization strategy. The development for future port and container transportation is a big challenge for such small and medium size ports.

3. Digitization and Digitalization

The two terms, ‘digitization’ and ‘digitalization’ often are confused. According to Merriam-Webster[2] dictionary, digitization refers to conversion of analogue data into digital form i.e. binary digits, so that it becomes understandable by the computer. Digitalization signifies the adoption of digital or computer technology by the organization or industry. So, it can be said that digitization is about moving from traditional paper-based or manual work to an electronic version, which is more efficient. And digitalization is having a coherent cluster of digitized activities in the organization or industry for the purpose of simplifying and enhancing the efficiency and performance of the organization or industry. Robert (Wachal, 1971) composed an essay on the subject of humanities and computers in which the author penned about digitalization and its implications on the society. The topic has been under research since then.

The integration of information and communication technologies and the global connectivity of these technologies have enabled computers, telecommunication devices and networks to

[1] https://southbaltic.eu/-/connect-2-small-ports
[2] https://www.merriam-webster.com/dictionary/digitise

collaborate and to work together (exchange information) locally and globally (Karakas, 2009). In the author's view these digital technologies have shrinked the economic boundaries and world is becoming a global village. Kasari further points out that this convergence has been observed due to innovations in technology, such as by digitization (Karakas, 2009). Today, we are progressing towards a digital ecosystem i.e. digitalization of processes, organization and even industry.

We can say that in the start there are discrete digitized processes or operations, which are with the progression of digital frontiers integrated with other processes or operations enabling a more holistic view of the organization, facilitating better coordinated planning and execution of activities. Hence, digitization, in our view, is a step towards digitalization, which is about implementing new business models that have new value propositions. This can be achieved if organization fathom a digital strategy, incorporate digital workflows and processes, and have integrated systems that assist in better coordination and analytical operations, and remain open to embrace future technologies. Digital transformation or digitalization is being digital at its core and an ongoing journey that aims at simplifying and enhancing the efficiency and performance of the organization.

Within the context of this study we refer to digitalization as an umbrella term to refer to different levels of digitization adapted from (Gardeitchik et al., 2017). Digitalization Level 0 refers to no digitization. Digitalization Level 1 signifies digitization of an individual process or operation in the port. Digitalization Level 2 indicates that the operations or processes are integrated with other processes or activities and work together to achieve efficiency. Digitalization Level 3 is a step further, when the port is integrated with hinterland operations. Whereas, digitalization Level 4 is having multiple ports to collaborate and coordinate their activities as an attempt to realize the notion of connected ports. We view digitalization as an ongoing process for the port and the maritime industry where the journey begins at lower digitalization levels and propagates to a higher one.

3.1 Digital Transformation in Maritime Ports

The digital innovations are modernizing the port industry steadily (Heilig et al., 2017a). The information technology has been a critical proponent for the port development (Kia et al., 2000) (de Gijt et al., 2010) (Mlimbila and Mbamba, 2018). Various researchers conducted studies on ports worldwide to identify how ports and terminals are benefitting from digital technologies (Carlan et al., 2017), (Heilig et al., 2017a), (Kia et al., 2000), (Mlimbila and Mbamba, 2018) and (Wisesa et al., 2018).

In (Heilig et al., 2017a), they provide a classification of three generations of digital transformation in marine ports. First generation began with containerization, from 1960 and went through 1989, during which paperless procedures were initiated; electronic shipping documents were introduced, electronic data interchange was developed, and terminal operating systems were used. In the second generation (1990 to 2009) procedures were automated with the adoption of laser, Radio-frequency identification (RFID), Global Positioning System (GPS), and Optical Character Recognition (OCR) systems. During this era the first automated container terminal was commenced; European Container Terminal in Rotterdam and Netherlands, and various truck appointment systems and global alliances were made. For example, (Kia et al., 2000) emphasized on the use of computerized container control system to improve the container terminal's operating efficiency. The simulation case for the Port of West Coast, USA and Port of Melbourne, Australia was presented to encourage use of electronic devices to identify congestions at the container terminal, as a result, the waiting time for straddle carrier was reduced clearly. Digital innovation in the port of Singapore has been disruptive, (Lee-Partridge et al., 2000) presented the case how the port leveraged the information technologies to stay competitive in the industry.

In the third generation, i.e. since 2010, there has been advances in mobile Cloud platforms to allow real-time information access, sensors have become Internet-enabled (IoT) and AI have helped the concept of automation in terminal equipment to become a reality. There has been wide use of decision support tools to help decision makers in capturing and analyzing the large amounts of available information. As an example, the Port of Melbourne has a community-based locally developed booking system that can evenly distribute trucks in the container yard, reduce congestion and maintain shifting of containers (Wisesa et al., 2018). It acts as a platform where all the port stakeholders can come together creating transparency and obtain shipment updates. In (Mlimbila and Mbamba, 2018), researchers argue that having information systems employed at the Port of Dar Es Salaam port, Tanzania can not only improve organizational capability but can also facilitate the on-time deliveries and bring reduction to trucking costs. In (Carlan et al., 2017), authors list 32 innovative cases from the Port of Antwerp for facilitating information exchange to track and monitor the cargo. It seems that the operational efficiency of container terminals is linked with digitalization for which there has been a realization within the maritime community.

While the discussion around the emerging digital technologies, such as AI, IoT and Blockchain and foundational digital enabler Cloud Computing is ongoing in the port community, some ports it seems are moving ahead with the implementations. Port of Rotterdam[3] and Port of Hamburg[4] are making the information flow, traffic flow and cargo flow more efficient by leveraging real-time information exchange, IoT enabled sensors and actuators that are autonomous and intelligent. A recent pilot study was conducted in which containers from the Port of Rotterdam were shipped to the Port of Newark using a

[3] https://www.portofrotterdam.com/en/doing-business/logistics/cargo/containers/50-years-of-containers/the-robot-is-coming
[4] https://www.hamburg-port-authority.de/en/hpa-360/smartport/

Blockchain that was implemented to create a joint electronic shipment ledger providing real-time shipment information to the involved entities[5].

In this study, an attempt is made to identify and analyze scientific literature on the state-of-the-art of the emerging technologies that are at the digital frontier. The choice of specific technologies was made because these technologies are seen as foundational enterprise technologies of change imparting confidence in businesses and industries to adapt and experience digital forefronts (Briggs et al., 2019). The Gartner research also resonates similar strategic technology trends for 2018 (Panetta, 2017) and 2019 (Panetta, 2018) to drive the digital transformation. The authors in (Heilig et al., 2017a) call novel IT delivery model (Cloud Computing), pervasive computing (e.g., IoT, cyber-physical systems), Blockchain, and tools to support real-time data science (Artificial Intelligence) as key enablers for digital transformation or information system-enabled organizational transformation. To limit the scope of the study other emerging technologies such as Augmented Reality, Virtual Reality, 5G, cyber-security and etc. are not considered for this investigation.

3.2 Digital Technologies: Definitions

In this section we define the underpinning technologies that formulate the review and explain the extent of the technology's scope within this literary review.

According to (Kaplan and Haenlein, 2019), AI is defined as, "*system's ability to correctly interpret external data, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation*" Colloquially, the term AI is applied when a machine mimics cognitive functions that humans associate with other human minds, such as for learning and problem solving (Russell and Norvig, 2010).

> "*Blockchain, like the Internet, is an open, global infrastructure that allows companies and individuals making transactions to cut out the middleman, reducing the cost of transactions and the time lapse of working through third parties. The technology is based on a distributed ledger structure and consensus process. The structure allows a digital ledger of transactions to be created and shared between distributed computers on a network. The ledger is not owned or controlled by one central authority or company and can be viewed by all users on the network*." (Underwood, 2016)

As defined by NIST (Mell and Grance, 2011), "*Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources; networks, servers, storage, applications, and services that can be rapidly provisioned and released with minimal management effort or service provider interaction*", thus increasing agility and reducing costs. With the widespread applications and

[5] https://www-03.ibm.com/press/us/en/pressrelease/51712.wss

advantages of the Cloud model there exists security issues which are being addressed by the community (Zissis and Lekkas, 2012) (Anwar, 2013).

The work of (Minerva et al., 2017), defines IoT as a system that has the following set of features: a) *interconnection of things,* where "thing" refers to any physical object that is relevant from a user or application perspective; b) *connection of things to the Internet*; c) *ubiquity* which means system available anywhere (or better globally) and anytime (or better always); d) *sensing and actuation capability*, i.e. sensor and actuators connected to the things; e) *embedded intelligence*, i.e. smart and dynamic objects with emergent behavior and embedded intelligence and knowledge; f) *interoperable communication capability*; g) *self-configurability*; and h) *programmability*.

4. Research Method

4.1. Search Strategy

The study follows Systematic Literature Review (SLR) (Kitchenham et al., 2009) methodology. Important concepts were translated to keywords and abbreviations. This helped to identify keywords related to container terminal and for the digital technologies under investigation. Since the focus of the study, as motivated in Section 3, is on specific set of digital technologies, hence, the exact keywords such as Artificial Intelligence, Blockchain, Cloud Computing and Internet of Thing(s), in addition to their variants such as; AI, automation, bitcoin, Block-chain, Block chain, Ethereum, cryptocurrency, distributed-ledger, distributed ledger, ledger technology and IoT were used in combination with container terminal variants; container terminal(s), container port(s) and TEU.

Since the objective of the study is to capture scientific work, the search strings were run on two main academic peer-reviewed scientific databases; Scopus, which is a comprehensive bibliographic database and in ISI Web of Science (WoS) which covers high impact factor journals published in English (Chadegani et al., 2013). The search was conducted by using the title, abstract and keyword fields without using any limitation on the year of publication.

The papers were filtered at different stages of the literature survey, as seen in Table 1. As part of Stage 1 exclusion criteria 1-3 were applied using the filters available on research repositories. In Stage 2 the metadata from the two databases was exported and stored into a Microsoft Excel sheet and author 1 screened through the title and abstract to refine the results. MS Excel's conditional formatting was used to highlight and remove duplicates manually. At the end of Stage 2 there were a total of 111 articles (out of 286). In Stage 3, exclusion was based on criteria 6 and 7, where author 1 screened full text of the studies to filter researches with emphasis on sea-side topics or topics beyond the container terminal gate as explained in scope of the study in Section 2.1.1. Similarly, studies that revolved around performance or comparison of optimization algorithms were taken out. Some studies had multiple occurrences, these were not picked by MS Excel duplicate feature as the titles were different. The latest occurrence of the study was kept while previous ones were dropped. The result of the selection process yielded 57 articles.

Table 1 – Stages and Exclusion Criteria in Systematic Literature Review

Stages	Studies	Criteria
Stage 1 (filters in Scopus and WoS)	286	1. Exclude studies not available in English
		2. Exclude studies except journal articles, conference papers and book chapters
		3. Apply subject or research area filter to refine related results
Stage 2 (manual)	111	4. Exclude papers in which focus was not on container terminal or that research on seaside operations such as dredging, stowage or tugboat scheduling; or about vessel emission or safety; or beyond the gate of the terminal, such as studies about rail planning
		5. Exclude duplicates (15 title matches)
Stage 3 (manual)	57	6. Exclude papers that do not focus on container terminal operations or processes in combination to the use of digital technology under investigation
		7. Remove (previous) copies of studies written by same author(s) on a similar topic but have a different title or source

4.2. Search Synthesis and Classification Matrix

Since the focus is on operations management and processes in container terminal and ports, the literature survey synthesis was conducted based on a classification matrix proposed in Table 2, which includes different aspects of the container terminal or port. The horizontal axis is grouped into 4 categories: container terminal operation types, container terminal processes, technology and research. The vertical axis lists the authors and year of the publication.

The attributes in the operation group include: vessel (or shipside) operations such as loading and unloading of containers, intralogistics operations, berth/quay operations, yard operations and the operations at gate. The attributes in container terminal processes include information exchange (such as documentation or bill of lading), tracking and tracing of container and other equipment, sorting and processing of containers in the yard, resource management for equipment and space, scheduling of operations and resources and if the study advocates integrated process approach. Technology group records data on the four technologies that are focus of this study: AI, Blockchain, Cloud Computing and IoTs. The research has 2 attributes; for topic and validation approach. All the attributes of the classification matrix can have either, Yes (Y) or No (N), except description of the research topic and validation with can have either of these options: Conceptual, Review, Design, Model, Simulation, Experiment, Case Study or Implemented. The classification chart presents the quantitative visualization of the data extracted from the selected studies under survey. It helps in categorization and comparison with other primary studies. The matrix is scalable in terms of adding new attributes such as another technology type.

Table 2 - Research Classification Matrix

Publication		Operation Type					Process Type						Technology Type				Research	
Author(s)	Year	Vessel side	Intra-logistics	Quay/ Berth	Yard	Gate	Info. exchange	Tracking/ Tracing	Sorting/ Proc.	Resource mgmt.	Sched.	Integrated proc.	AI	Block-chain	Cloud	IoT	Main Topic	Validation
Legato P., Mazza R.M.	2018	N	Y	Y	Y	N	Y	N	Y	Y	Y	Y	Y	N	N	N	DSS	Experiment
Stavrou, D.,et al.	2018	N	Y	N	Y	N	N	N	Y	Y	Y	Y	Y	N	N	N	Automation	Simulation
Gaete M., et al.	2018	N	N	N	Y	N	Y	N	Y	Y	N	N	Y	N	N	N	DSS	Simulation
Hill A., Böse J.W.	2017	N	Y	N	N	Y	Y	N	N	Y	Y	N	Y	N	Y	N	DSS	Case study
Heilig L., et al.	2017	N	Y	N	Y	N	Y	Y	N	Y	N	N	Y	N	Y	N	Cloud DSS	Experiments
Castilla-Rodríguez I., et	2017	N	Y	Y	N	N	N	N	N	Y	Y	N	Y	N	N	N	DSS	Simulation
Supeno H., et al.	2016	N	Y	Y	Y	N	Y	Y	N	Y	Y	N	Y	N	N	N	3D sched. Sys.	Simulation
Huang Q., Zheng G.	2016	N	Y	Y	Y	N	N	Y	N	Y	N	N	Y	N	N	Y	AGV route	Simulation
Choe R., et al.	2016	N	Y	Y	Y	N	N	Y	N	Y	N	N	Y	N	N	N	AGV dispatch	Simulation
Tierney K., Voß S.	2016	N	N	N	Y	N	N	N	Y	Y	N	N	Y	N	N	N	Premarshalling	Experiments
Tsertou A., et al.	2016	N	N	N	N	N	Y	N	N	N	N	N	N	N	Y	N	Info. Portal	Design
Ursavas E.	2014	Y	Y	Y	N	N	Y	N	N	Y	N	N	Y	N	N	N	DSS	Case study
Heilig, L., Voss, S.	2014	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Cloud DSS	Design
Kocifaj M., Adamko N.	2014	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	Model	Simulation
Zhen L.	2014	N	N	N	Y	N	Y	N	Y	Y	N	N	Y	N	N	N	Yard DSS	Experiments
Chen L., et al.	2013	N	N	N	Y	N	Y	Y	Y	Y	N	N	Y	N	N	Y	Resource mgmt. mod	Case study
Fazlollahtabar H., Saidi	2013	N	Y	Y	Y	N	N	Y	N	Y	Y	N	Y	N	N	N	AGV sched.	Review
Lalla-Ruiz E., et al.	2012	Y	N	Y	N	N	N	N	N	Y	N	N	Y	N	N	N	AI tabu search	Simulation
Rodrigues L.M., et al.	2012	Y	Y	Y	Y	N	N	N	Y	Y	Y	N	Y	N	N	N	MAS	Simulation
Wasesa M., et al.	2012	N	N	N	N	N	Y	Y	N	Y	N	N	Y	N	N	N	MAS	Simulation
Salido M.A., et al.	2012	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	N	N	DSS	Implemented
Shetty R., et al.	2012	N	N	N	Y	Y	Y	Y	N	N	N	N	Y	N	N	Y	OCR	Review
Cai B., et al.	2011	N	Y	N	N	N	N	N	N	Y	Y	N	Y	N	N	N	ASC sched.	Simulation
Ter Mors A.W.	2011	N	Y	N	Y	N	N	Y	N	N	N	N	Y	N	N	N	Robotization	Experiment
Salido M.A., et al.	2011	Y	N	Y	N	N	N	N	Y	Y	N	N	Y	N	N	N	DSS	Model
Zhang C., et al.	2011	N	Y	N	Y	N	Y	N	Y	Y	N	N	Y	N	N	N	DSS	Implemented
Shi X., et al.	2011	N	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	Y	RFID applications	Review
Lee M., et al.	2011	N	N	N	N	Y	Y	Y	N	Y	N	N	Y	N	N	Y	Gate system	Implemented
Huynh N., Walton C.M.	2011	N	Y	N	Y	Y	Y	Y	N	Y	Y	N	Y	N	N	N	DSS	Simulation
Ngai E.W.T., et al.	2011	N	Y	Y	Y	Y	Y	Y	N	Y	N	N	Y	N	N	Y	DSS	Case study
Zhao N., et al.	2010	N	Y	N	Y	N	Y	N	Y	Y	N	N	Y	N	N	N	DSS	Case study
Yuan S., et al.	2010	N	Y	Y	Y	N	N	N	N	Y	N	N	Y	N	N	N	ASC sched.	Simulation
Park T., et al.	2010	N	Y	Y	Y	N	N	Y	Y	Y	Y	N	Y	N	N	N	GA for remarshalling	Experiments
Chen Y., et al.	2010	N	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y	N	N	N	VR	Design
Guo X., et al.	2009	N	Y	N	Y	N	Y	Y	N	Y	N	N	Y	N	N	N	DSS	Simulation
Salido M.A., et al.	2009	N	N	N	Y	N	N	N	Y	Y	N	N	Y	N	N	N	Model	Experiments
Guiliang Z., Lina M.	2009	N	N	N	Y	N	Y	N	Y	Y	N	N	Y	N	N	N	DSS	Simulation
Cheong C.Y., et al.	2009	Y	N	Y	N	N	N	N	N	Y	Y	N	Y	N	N	N	DSS	Simulation
Yan N., et al.	2008	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	N	N	MAS	Design
Guo X., Huang S.Y.	2008	N	Y	N	Y	N	N	N	N	Y	Y	N	Y	N	N	N	Crane dispatch	Experiments
Maione G.	2008	Y	Y	Y	Y	N	Y	N	Y	Y	N	Y	Y	N	N	N	MAS	Simulation
Hoshino S., Ota J.	2008	N	Y	N	N	N	Y	Y	Y	Y	N	N	Y	N	N	Y	Robotization	Simulation
Dougherty E.	2008	N	Y	N	N	N	N	N	Y	N	N	N	Y	N	N	N	Automation	Review
Fancello G., et al.	2008	N	Y	N	N	N	Y	N	N	Y	N	N	Y	N	N	N	DSS	Model
Eun Y.A., et al.	2007	N	Y	N	Y	N	N	N	N	Y	Y	Y	Y	N	N	N	Sched. method	Simulation
Costa G., et al.	2007	N	N	Y	Y	N	Y	Y	N	N	N	N	Y	N	Y	Y	DSS route	Model
Chowdhury M.A., et al.	2007	N	Y	N	Y	N	Y	N	Y	Y	Y	N	Y	N	N	N	Message flow	Model
Lokuge P., Alahakoon D	2007	Y	N	Y	N	N	Y	N	N	Y	Y	N	Y	N	N	N	MAS design	Experiments
Su W., Bo M.	2006	Y	Y	N	N	N	Y	N	N	Y	Y	N	Y	N	N	N	Equipment sched.	Simulation
Kim K.H., Lee J.-S.	2006	N	N	N	Y	N	N	N	N	Y	N	N	Y	N	N	N	Locating containers	Experiment
Kozan E., Corry P.	2005	N	Y	N	Y	N	Y	Y	Y	Y	N	Y	Y	N	N	Y	DSS	Conceptual
Hartványi T., et al.	2005	N	N	N	N	N	Y	N	N	N	N	N	Y	N	N	N	Info. Mgmt	Conceptual
Rida M., et al.	2003	N	Y	N	Y	N	Y	N	Y	Y	Y	Y	Y	N	N	N	Policy test-bed	Simulation
Lee John C.M., et al.	1999	N	N	N	N	Y	Y	Y	N	N	N	N	Y	N	N	Y	ACR	Implemented
Gambardella L.M., et al.	1998	N	Y	Y	Y	N	Y	N	Y	Y	Y	Y	Y	N	N	N	DSS	Simulation
Dredging & Port Constr	1997	N	N	N	N	N	Y	Y	Y	Y	N	N	Y	N	N	Y	Automation	Review
Itmi Mhamed, et al.	1995	N	Y	Y	Y	N	Y	N	Y	Y	N	Y	Y	N	N	N	MAS	Model

5. Literature Review Results and Analysis

We notice that exploitation of digital technologies that are under the scope of the study for container operations management was from mid-nineties. This may be due to the focus of the research review which intended to capture selected digital technology enablers (Heilig et al., 2017a).

It is interesting to observe that early years of 2000 also had few publications on the subject, the pace increased from 2006 onwards as evident from the classification matrix in Table 2. A noticeable trend observed was that an increasing interest in technology publications around the container shipping port sector was over the last decade (2008 - 2018) contributing to 77% of the articles from this review.

The classification matrix of 57 publications according to the suggested classification criteria described in Section 4.2 is presented in Table 2. The use of exclusive values, such as Yes or No is explicit in showing what was or was not covered in the literature. No studies exist on the use of Blockchain in ports and container terminals using our systematic literature strategy. The analysis of the selected studies is shared below.

5.1 Artificial Intelligence (AI)

Multi-agent systems (MAS): MAS were evidently researched to cater allocation issues, such as for container transportation from berth to yard or when allocating the equipment to carry the container within terminal (Itmi et al., 1995). The authors model a reactive agent that has goals and cooperative behavior to handle the container movements, and N-puzzle approach to position container in a storage block in the yard. A conceptual study on having multiple software agents for a distributed information management system was presented in (Hartvanyi et al., 2005) to improve cooperation among terminal managers, customers and carriers via the information connections. (Lokuge and Alahakoon, 2007) showed agents can enable automated scheduling of vessel to berth if they have certain beliefs, ability to learn through neural-network based intelligent component and adapt when backed up by a knowledge module. Another discrete-event simulation MAS approach was given in (Maione, 2007) where container agents, crane agents, trailer agents and truck agents interact and work together. (Nannan Yan et al., 2008)'s MAS architecture offered the integration of heterogeneous information from multiple operations within the terminal setup to offer a centralized and structured dispatching system. The basic container terminal ecosystem was created employing ABAsim layered architecture. It had an agent for storage, equipment handling, an agent to coordinate storage and equipment handling, gate agent, Automated Guided Vehicle (AGV) agent, path finding agents, infrastructure and utility agents to dispatch and manage cooperation (Kocifaj and Adamko, 2014). The agent model of Kocifaj was then merged with a transportation terminal simulation tool called Villion.

Artificial neural-network: (Lee, 1999) tested an automatic Character Recognition System (CRS) to identify vehicle and container numbers from various distortions. They incorporated an artificial neural-network with an expandable training set. Details on applications of License Plate Recognition (LPR) and OCR in the context of supply chain can be found in (Shetty et al., 2012).

Decision Support System (DSS): The concept of an integrated DSS was proposed to reduce complexity and improve usability in (Kozan and Corry, 2005). The system called E-Intermodal was conceptualized to perform container bookings and to track and store live yard information to plan the container pickups. They proposed the use of 2 IoT enablers Global Positioning System (GPS) and RFID to trace the containers in the terminal. A decision support system model for maintenance managers was presented by (Fancello G et al., 2008) to record, analyze and evaluate maintenance and performance for intra-logistic machines such as cranes.

The berth allocation problem was addressed with the help of multi-objective evolutionary algorithm with incorporation of Pareto optimality ranking. The ranking allows decision maker to take informed decisions on berth schedules (Cheong et al., 2009). We also see work on an intelligent container storage allocation system (Guiliang and Lina, 2009) and for yard crane allocation (Zhang et al., 2011) (Salido et al., 2012). Salido advocates a coordinated approach where the authors chain container sorting, berth allocation and quay crane allocation in an integrated DSS. Visualization of an automatic trailer dispatch schedule scheme was given in (Zhao Ning et al., 2010). Deciding container stacking with respect to storage policy was presented by (Gaete et al., 2018). The case study showed prospect of reduced container reordering.

An integrated artificial intelligent system which combines berth allocation and planning of container shuffles was also under research (Salido et al., 2011) where the berth allocation was done using metaheuristic algorithm and later the heuristic planner calculated the reshuffles needed to arrange the containers. This decision tool can in turn assist the planner to choose suitable solution. Another work on real-time yard storage allocation system for uncertain conditions was done (Zhen, 2014). A model-driven support system for human-operated handling machines such as rail-mounted gantry cranes and straddle carriers was put forth by (Legato and Mazza, 2018) where they expended what-if simulation runs to grasp the situation. A similar work that coalesced 3 issues i.e. berth allocation, quay crane allocation and quay crane scheduling was put forward by (Ursavas, 2014) where the author proposed an interactive decision support tool to make a suitable verdict.

There is discussion about information system such as truck appointment system (Huynh and Walton, 2011) to control the vehicle arrival and plan schedules for related operating scenarios. A more sophisticated decision-making with a forecasting engine was also found (Hill and Böse, 2017).

Simulation: The information management systems allow the terminal managers to monitor and control the processes. Simulation technique is a good way to process raw data and get an insight on the operation under observation, as done by various authors. (Su and Bo, 2006) applied simulation technique to mimic equipment scheduling and further optimized the results with Ant Colony algorithm. (Gambardella et al., 1998) dealt with the allocation of yard and cranes to the container by proposing a decision support tool for planning purposes. The authors used simulation to test the decision policies and compared with actual experiences. (Rida et al., 2004) also test and run what-if scenarios to evaluate management policies via a visual interface on the simulator. A real-time information exchange model to ease electronic message flow between multiple stakeholders; shippers, agents, freight forwarders, Main Line Operators of the terminal was shared by (Chowdhury et al., 2007). Another simulation based decision tool was given in (Guo et al., 2009) for yard crane load division. The work predicts vehicle arrival from available information tracking system to mimic real-time what-if simulations and deliver a sequence for yard cranes. The concept of exploiting virtual reality for mirroring a 3D simulation of the automated container terminal was also examined (Chen et al., 2010). The work on improved scheduling for loading and unloading of containers to/from the ship was shared by (Rodrigues et al., 2011) based on different agent priorities. They simulated the model of the robotic-based automation system on Netlogo to gauge the presented policies. Like other studies, (Castilla-Rodríguez et al., 2017) also exploited simulation technique to interpret a digital view of various processes and operational scenarios at the terminal.

Search Algorithms: Optimization is not a practical approach to solve space allocation issue argues (Kim and Lee, 2006) where the authors propose search algorithm while fulfilling certain constraints. The discussion around Artificial Intelligence was mostly on how to manage and optimize the routes for intra-logistic vehicles such as (Guo and Huang, 2008) where authors modify A* search and predict vehicle job finishing time to offer optimal dispatching. Proposition of real-time scheduling of equipments such as straddle carriers and yard cranes was discussed in (Ahn et al., 2007) where timetables were made using heuristics and later analyzed to spot possible delays so necessary adjustment in plan could be made. A model for autonomous straddle carriers to transfer containers from ship to yard was presented in (Yuan et al., 2010) where nearest-greedy heuristic was implemented to optimize the operation. We observe discussion on intelligent container stacking models (Salido et al., 2009) and on container remarshalling schedules by exercising dynamic genetic algorithm (Park et al., 2010). (Lalla-Ruiz et al., 2012) proposed an AI based hybrid metaheuristic that combines Tabu search with Path Relinking to dynamically assign berth to the vessel. The scheduling system for container truck uses 3D visualization and Genetic Algorithm for optimization the travel distance of trucks for loading and unloading (Supeno et al., 2015). Work on reducing the number of container movements (or rehandles) was presented by (Tierney and Voß, 2016), where the authors proposed a novel solution approach to the container pre-marshaling problem using the A* and IDA* algorithms combined with several novel branching and symmetry breaking rules that significantly increases the number of pre-marshaling instances that can be solved to optimality.

Automation: A review presented in a trade journal gave highlights of the need for digitizing the documents that arrive with the container ships and shed light on the robotic transformations in that era. The article mentioned about the Robotic Container Handling Machine that can handle and store 14000 containers simultaneously, AGVs introduction at the European Container Terminals (ECT), Container Tracking and Identification System (CTIS) and CONLOC which is a system to verify, track and locate containers ("World's ports see automated future," 1997). The AGVs and automated transfer cranes (ATCs) are seen as reactive robots in (Hoshino and Ota, 2008) where the robots maintain control over dynamic operational environment by communicating with neighboring robots, thereby improving its reliability and hence, throughput. Similar idea was propagated by (Ter Mors, 2011) to discern conflict-free routes for AGVs exercising Pareto-optimal planning mechanism. Scheduling for autonomous straddle carriers have also been in investigation (Binghuang Cai et al., 2011) and in an extensive review of AI methodologies such as use of Petri nets, UML, cellular manufacturing systems (Fazlollahtabar and Saidi-Mehrabad, 2015) to program AGVs. To triumph autonomous container truck (ACT) path planning (Huang and Zheng, 2016) use Ant-colony optimization whereas the ultrasonic sensors on truck provide details of the otherwise unknown environment. According to (Stavrou et al., 2018) automation can improve efficiency of logistics. The authors develop a method to assign containers to robots and coordinate to execute their tasks, they make use of mixed-integer linear programming tools.

In (Choe et al., 2016) the authors proposed an online preference learning algorithm named OnPL that can dynamically adapt the policy for dispatching autonomous vehicles to changes in the environment in an automated container terminal. The autonomous vehicles are dispatched with the goal of to maximize the quay crane productivity, and to minimize the carbon dioxide emissions. The performance of the OnPL algorithm has been compared with other scheduling algorithms showing that OnPL is fast and perform better in dynamic environments.

5.1.2 Cloud Computing

When it comes to use pervasive technologies like IoT and Cloud Computing in container terminal, we notice only few researches. During the investigation, Cloud technology was found to be discussed more of an enabler for other technologies including IoT. A mobile location-aware prediction model was shared by (Costa et al., 2007) where GPS/geo-sensors, GIS, GPRS, RFID and Wi-Fi technologies together track and identify the location of container. The data mining technology helps in path prediction to assess possible bottlenecks in the container route.

Having real-time transparency of available information is of prime value to execute dynamic port processes and operations. Converging operational data from the information systems and sensory input from IoT scanners and exploiting the Cloud and communication technologies permits an array of opportunities. The work of (Heilig and Voß, 2014) depict the concept and practicality of the same.

(Tsertou et al., 2016) emphasized for a Cloud-based information portal for the stakeholders linked with IoT sensors for real-time information analytics relieving especially the small-medium ports and other entities from complexities of handling multiple information interfaces. In addition to sharing essential information it also shared about incorporating financial settlement and feedback features. (Heilig et al., 2017b) shared an idea of having an integrative mobile Cloud platform for real-time inter-terminal truck routing.

5.1.3 Internet of Things (IoT)

With the progress from barcode and magnetic strip, now the RFID and Optical Character Recognition (OCR) tags are used at container terminal gate to check-in the truck and container (Lee, 1999) (Lee et al., 2011) (Shetty et al., 2012). The RFID tag refers to the digital encoded label, which is linked with a software system that records the data. In the survey, such papers are classified in the context of IoT, as it lays foundation for Internet of things and enables automation. An extensive review on the applications of RFID in container terminal setup in given in (Shi et al., 2011).

(Lee et al., 2011) refer to the use of smart RFID labels to track container journey in the terminal and suggest it being linked to the overall information workflow to assist in the custom documentation. The authors say the tag could serve as a package of document having details such as goods inside the container and other related shipping information, which could be used for follow-up documentation such as Bill of Lading. (Lee et al., 2011) propose compliance of RFID with OCR and Road Top Unit (RTU) devices to enable a fully automated escort of the container at the gate.

(Shetty et al., 2012) advocated the same concept of using RFID with OCR, License Plate Recognition (LPR) leveraging the use of Internet to identify and trace the freight, and to manage the yard space and handling equipment more efficiently. One articled identified, shared the concept of using wireless technology to trace the locations of objects in container terminal (Costa et al., 2007).

A prototype of a decision support system (Ngai et al., 2011) was designed to enable real-time tracking of intra-logistic equipments and vehicles in the container terminal so the assignments of Rubber Tyre Gantry (RTG) cranes and vehicles can be done. The case study demonstrated that providing the terminal manager with the complete and right information can allow them to make more informed decisions. An emphasis was made on identification of container position (Wasesa et al., 2012) to align other operations such as container sorting and efficient truck pickups.

With IoT it becomes possible to trace the container and keep track of train or vehicles. It comes in as an essential constituent to be able to see beforehand the arrival situation and to plan the yard storage and movements of both subjects within the terminal efficiently (Chen et al., 2013).

6. Discussion

Though, the reception of digital technologies, such as those highlighted in this study, in the container terminal domain, has been slow, but it has been steady and is evolving. Modern technologies require hefty costs to setup the needed infrastructure and equipment, to develop new business model that assists in forming digital culture and to revisit the processes and operation workflows to make needed transformational adjustments. These capabilities are easier to find in a large container port setup as compared to small or medium container terminal. The question is how emerging and evolving technologies could be beneficial for smaller seaports. It is suggested that small and medium ports should consider some of the areas that have been adapted from the studies under this review. It is recommended that small container terminals consider one problem at a time and devise a solution that suits their budget and value proposition. For instance, it is not advisable to invest in AGVs in a small terminal's yard or to enable an IoT suited infrastructure without considering the large power and maintenance costs or human resource education costs that it will incur. Also, the stakeholders could consider RFID tags with other sensors available in market, such as WIFI tags to bring down the overall costs.

Understandably, due to the technicalities involved in the container transportation; efficient documentation and information management is in high demand. The results from the survey indicate the use of technology to facilitate the information exchange and documentation has not been commonly implemented. There are theoretical studies to support, but few have gone ahead to develop and use it, which opens up other venues to expand the work and examine the barriers that maybe hindering digital transformation in this sector.

7. Conclusion and Future Work

An extensive scientific literature review was conducted to understand the current "state-of the-art" of technologies that are researched regarding to container terminal operations and processes. It was observed that many papers had detailed work on AI techniques for optimizing solutions, simulation was a common practice to visualize various scenarios, multi-agent systems were under spotlight and so were decision supports system for resource allocation and scheduling processes. Empirical research on information exchange between the teams on ground and decision makers was lacking. Use of Cloud and IoT was discussed in terms of survey and design papers. It is recommended that more applied empirical studies be conducted in this evolving field of container logistic digitalization with grounded validations through implementations and trails in the actual container terminal environment.

The scarcity of evidence-based results on the matter stresses further research consideration from practice and industry.

Scientific evidence on use of Blockchain within the operational setup of container transportation was missing. It is worth mentioning that the first iteration of searching literature did not result in any papers on Blockchain, hence the criteria was relaxed only to find out if any literature exists on the subject. This furnished us with 8 studies. However, these are not included within this review just to be consistent with the SLR protocol of other concepts. As for future work, additional databases and a relaxed search criterion could be utilized in order to obtain further studies on Blockchain and container terminals.

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