OPTIMIZATION APPLICATIONS IN SEAPORT CONTAINER TERMINAL OPERATIONS AND FUZZY LOGIC-BASED INTER TERMINAL TRUCKING

BUDDHI CHATHUMAL ALWIS WEERASINGHE

218049H

Degree of Master of Science

Department of Transport and Logistics Management
University of Moratuwa
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DECLARATION OF ORIGINALITY

I declare that this is my own work, and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or institute of higher learning and to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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(Buddhi A. Weerasinghe)

STATEMENT OF THE SUPERVISOR

The above candidate has carried out research for the Degree of Master of Science under my supervision.

Name of the supervisor: Dr. H.N. Perera

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ABSTRACT

Operations research techniques have helped optimize container terminal operations over the past decades and have been a regular feature of maritime logistics and maritime supply chain literature in addition to being in practice at container terminals across the globe. The first phase of the project, a systematic review systematically collates through Scopus and analyzes 1631 papers published in the domain to find the main research clusters and understand future research directions. Studies based on both quayside and landside planning are encapsulated for this research. Five research clusters that discuss simulation, scheduling and automation, quayside operations, integrated operations, and container transportation are identified based on author keywords of the systematically derived paper pool. In addition to that, the evolution of applying optimization techniques in container terminal operations planning is discussed in this study alongside the suggested trajectory of the research agenda under each cluster. The analysis finds that genetic algorithms, integer linear programming and heuristics are the most widely used operations research techniques in container terminal optimization. The review proposes the application of methods such as neural network, fuzzy logic and deep learning models related to artificial intelligence to widen our understanding of container terminal operations. The second phase of the project is conducted to optimize ITT truck flows in container terminals by following the research direction that is derived through the cluster, container transportation in the systematic review. The proposed model is developed using fuzzy logic in MATLAB software. The model can allocate ITT trucks based on the demand from terminal yards and current truck arrival rates at gatehouses. More industry and academia as well as inter-terminal collaborations are needed in future studies for enhancing ITT operations and the overall operations in container terminals.

Keywords: container terminals, systematic review, inter-terminal transportation, optimization, maritime logistics, fuzzy logic

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LIST OF ABBREVIATIONS

ITT	Inter Terminal Transportation
YC	Yard Crane
MCC	Multi-Country Consolidation
LCL	Less than Container Load
QC	Quay Crane
QGC	Quay Gantry Crane
RMG	Rail Mounted Gantry crane
RTG	Rubber Tired Gantry crane
SC	Straddle Carrier
SFD	Stack and Flow Diagram
YT	Yard Truck
SLPA	Sri Lanka Ports Authority
SAGT	South Asia Gateway Terminals
CICT	Colombo International Container Terminals
JCT	Jaya Container Terminal

LIST OF APPENDICES

1 INTRODUCTION

1.1 Background of the study

Container terminal operations planning is crucial for sustaining global supply chains. Any disruption that happens in container ports leads to make bottlenecks in supply chains that are connected globally. Therefore, optimizing container terminal operations results in providing a comfortable stage for global supply chains to be performed.

The study focuses the overall planning function in container terminal operations. Mainly the study consists of two phases. UNCTAD, (2020) reveals that the annual growth of maritime trade has fallen by 4.1% in 2020 due to the global COVID crisis. However, 140 million TEUs were transported around the world in 2020 (UNCTAD, 2020). Therefore, it is critical to understand the current research trends and reveal potential research paths for the growth of the container terminals industry.

The growth of the container ships fleet is 2.48% from 2020 to 2021 (UNCTAD, 2021). This figure proves that the supply of container ships is increased even though the pandemic disrupted the global supply chains. The container freight rates have shown a significant increase over the last years where it shows the importance of container transportation. Green operations are motivated through studies as well as practices due to pressure that is built by communities where it leads to decarbonization (UNCTAD, 2021).

New approaches such as dynamic scheduling (Gunawardhana et al., 2021) and integrated operations (Weerasinghe et al., 2022) are employed as the most recent trends. Weerasinghe et al., (2022) further claim that intensifying internal interfaces; quay to yard and yard to gate, can enhance the future operations of container terminals. Seaside operations, optimization, simulation, computer simulation, control system, numerical models, and planning are the key focuses on most recent trends in container terminal operations according to our evaluation of review studies within the scope (2.3.2).

Optimization and technologies have improved port operations to a greater level. Artificial Intelligence (AI) concepts such as machine learning have enhanced port operations according to Filom et al., (2022). In a nutshell, container port optimization should be focused as a key focus to build container port transportation to a higher level. Understanding the current trends of container terminal optimization will lead to reveal and improve future research directions.

1.2 Structure of the thesis

First, the literature review is conducted by starting the discussion on operations inside container terminals (2). Container terminal operations planning is the key focus of the study (2.2.1). Quayside (2.2.2) and landside (2.2.3) planning are discussed separately by understanding planning concepts under each area. Then the review studies are evaluated for identifying research gaps within container terminal operations more systematically (2.3). A systematic review (2.3.2) is conducted by reviewing previous systematic reviews under the scope to reveal research directions further.

Then phase one of the MSc project is conducted as a systematic review in container terminal operations optimization (3). First, the review methodology is explained (3.1). Then the bibliometric analysis is conducted (3.2) by introducing the status of the scope. Afterwards, the analysis is conducted including the discussion on planning functions (3.3.1) and identified research clusters (3.3.2).

As the second phase of the study, optimizing ITT truck flows in container terminals using fuzzy logic is conducted (4). After identifying the exact project, fuzzy logic is identified as the methodology to conduct the control system for ITT operations (4.2.2). After that, the analysis is conducted by building the fuzzy model (4.3). The ITT truck allocation (4.3.5) is introduced under two strategies. Then the discussion (5) is conducted for both phases and the study is summarized in the conclusion (6).

2 LITERATURE REVIEW

2.1 Operations inside container terminals

Seaport container terminals play a vital role in maritime transportation. Maritime transport is crucial for sustaining the supply chains around the world. Besides, containerized transportation represents 20% - 30% of the world maritime trade by volume (UNCTAD, 2021). Furthermore, approximately 70% of the cargo is handled by global seaborne container trade in terms of value (Dadashi et al., 2017). For instance, 815.6 million Twenty-foot equivalent units (TEUs) have been handled in container ports as the total throughput in 2021. Quayside operations and landside operations are the fundamental division that divides the container terminal operations (Böse, 2020). In quayside, loading and discharging operations are performed. The place where containers are stacked temporarily is identified as the yard. Containers are stacked until the connected outbound vessel comes or consignee send the truck to collect the containers (Chu et al., 2019).

Envisioned purpose and terminus of the containers are used in categorizing containers in this study. The fundamental terminal operations are originated by exports and imports. The containers that are dispatched via a vessel using waterborne routes can be identified as exports (Muravev et al., 2019). The containers that are imported via a vessel using waterborne routes can be identified as imports. These imports containers are dispatched and circulated inside the land (Mar-Ortiz et al., 2019). Transshipments can be introduced as the next category. Reshipment is another term to introduce transshipment in international trade (SLPA, 2015). A temporary stopover can be introduced as a transshipment port for that particular container (SLPA, 2016). First the transshipment container is discharged from the vessel and it is loaded to another vessel inside the same terminal (Zhou et al., 2016).

Inter-Terminal Transportation (ITT) is the next major operation that is well known as ITT (Wang et al., 2014). The container that is stacked in another terminal within the same port is shifted to the relevant terminal when the outbound vessel of the particular container calls. ITT containers are stacked temporary in the yard of the terminal where the outbound vessel that the containers are loaded similar to the export process. Until the discharged ITT containers are delivered from the terminal to the relevant terminal for outward movement, containers are stacked in the discharged terminal parallel to the imports process. Therefore, it can be concluded that loading, discharging, and transfer containers are the key categories inside the terminal yard including ITT containers (Cai et al., 2014). Figure 1 further explains the container terminal operations in operational perspective.

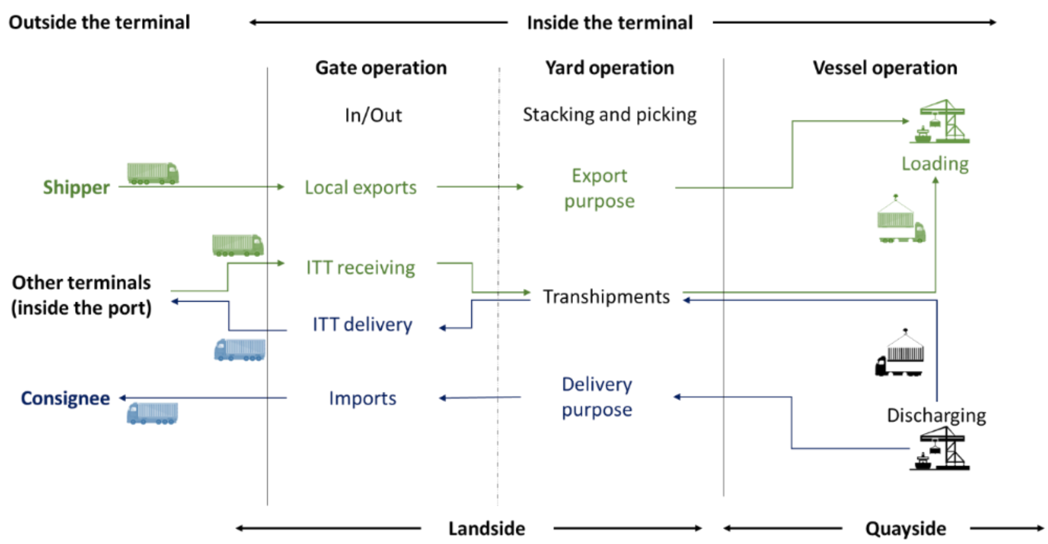


Figure 1: Container terminal operations - operations perspective

Source: Weerasinghe et al., (2022)

Quay Gantry Crane (QGC) is used in quayside operations. Interchangeably, Quay Gantry Crane is defined using the term quay cranes (QC) in studies as well. QCs perform loading and discharging operations in quayside (Bartošek & Marek, 2013). Stacking and picking are the key jobs for Yard cranes (YC) at yards. Rail Mounted Gantry crane (RMG), Rubber Tired Gantry crane (RTG), and Straddle Carrier (SC) are the three types of yard cranes that are widely used. Out of these, RTG is the most famous yard crane type (Guo & Huang, 2012). Less than Container Load (LCL) and Multi-Country Consolidation (MCC) can be identified as other process in container terminal operations as external functions where the operations need logistics facilities such as warehouses and transportation (SLPA, 2015). MCC containers can be arranged in different countries when it compares with other operations. Ports should facilitate logistics facilities such as warehouses and transportation for LCL and MCC operations (Bahadir & Akdag, 2019). LCL and MCC operations are excluded in this study since these types are operated in addition to the basic operations; exports, imports and transshipments.

2.2 Container terminal planning

2.2.1 Planning function

Container terminal planning is a multifaceted job. Global seaborne container trade is valued 60% of freight transportation in terms of value. The value is around 12 trillion U.S. dollars in 2017 (OECD & EUIPO, 2021). In other words, 60% of global freight transportation is affected by container transport efficiency. Container terminal planning is getting more and more complex while the needs of shipping lines are demanded in a dynamic environment (Kastner et al., 2020). Automation projects, optimizing port calls and port community systems are invested by highly ranked international ports focusing on providing a better service (UNCTAD, 2019). Every planning task is interconnected, and nothing can be identified that is disconnected in container terminal planning.

Time horizons are defined with specific timeframes in tactical level planning. However, specific tasks need trained human roles who are also decided in long term strategic planning. Quayside and landside operations are the key areas that are defined as the main division in container terminal planning (Jin et al., 2014). Quayside planning (2.2.2) and landside planning (2.2.3) are discussed in the next parts with sub planning tasks. Quayside planning is defined that includes all the planning tasks that are operated in quayside. All the tasks that are related to landside are called landside planning altogether. Operational perspective of containers is considered to develop this study. Exports, imports and transshipments, are the categories that are identified in terms of container terminal operations (Güven & Eliiyi, 2018). Containers that are transferred between terminals within the same port can be defined as transshipment containers (Cai et al., 2014).

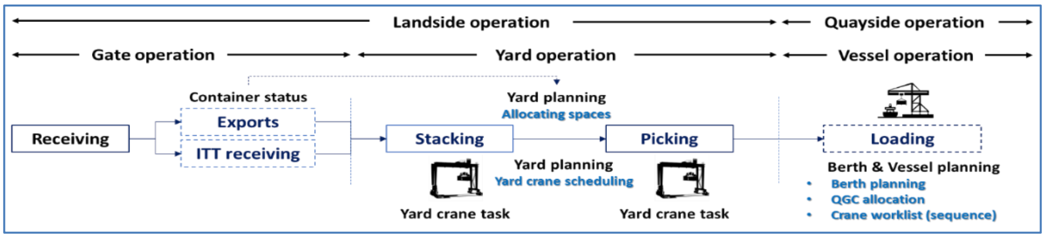


Figure 2 : Operational process of ITT receiving

Figure 2 explains how the ITT receiving process can be summarized into a process view. Gatehouses record the arrivals of Export containers when the reach to the gatehouses. Both automated and manual operations can be observed at gatehouses (Nellen et al., 2020). Gatehouses provide the yard location once the container reaches. The allocation is issued by following the stacking policies for arriving export containers. Studies that focus landside planning identify stacking policies as a significant area for research. Arriving containers is the category that explains the stacking problem for Exports (Güven & Eliiyi, 2018). Further, online stacking policies are employed in studies. Yard optimization has been focused by Güven & Eliiyi, (2014) in studying allocation problem and stacking policies. It is important to understand the receipt of containers in the ITT category inclusively since more studies focus on all inbound containers using trucks in one category as inbound containers. Factors, the type of cargo inside, the size, weight, port or location of discharge and outbound vessel or truck of the container are considered in deciding where to stack in the yard (Güven & Eliiyi, 2014).

The decision support systems consider the availability of yard cranes in studies (Mar-Ortiz et al., 2019). Exports and ITT receiving containers are considered in one category as loading containers leads to consider those in a similar process. Allocation decision affects the terminal efficiency significantly since reallocation generate additional crane and yard moves at yards (Caserta et al., 2012). Discharging process should be identified before going to the transit container process since discharging process directly involves deliveries from the terminal end. Imports, and ITT deliveries generate delivery tasks at yards.

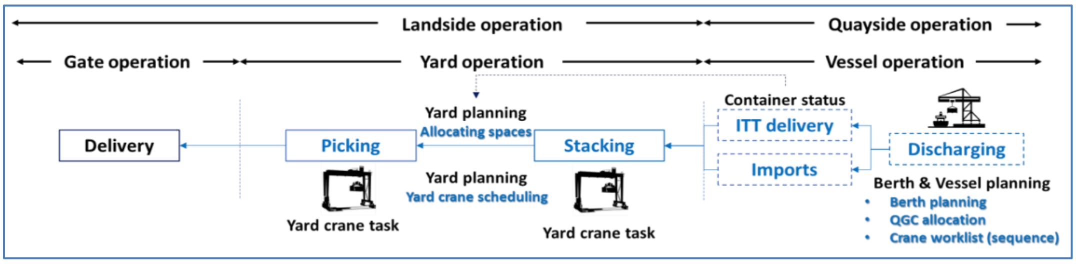


Figure 3: Operational process of ITT delivery

Figure 3 explains the import and ITT delivery operations process. The stacking locations at yards for discharging containers should be allocated before the containers are discharged from vessels (Güven & Eliiyi, 2014). Factors, the type of cargo inside, the size, weight, port or location of discharge and outbound vessel or truck of the delivery containers are considered in deciding where to stack in the yard (Güven & Eliiyi, 2014). Stacking policies play the key role in the yard allocation decision (Li et al., 2018). The yard allocation is given by following a similar process as in receiving process.

Once the import containers are discharged from the vessel, the containers are stacked at container yard. Internal terminal trucks or railroads are used to transport import containers (Güven & Eliiyi, 2018). Imports and ITT containers are picked as deliveries by ITT trucks as well as external trucks. First, consignee receives the cargo clearance from the terminal office. Then the permission is granted to allocate storage facilities to the container at terminal yards (Muravev et al., 2019). Gatehouses are optimized using queuing management and optimization concepts. It helps to reduce congestion at yards (Abeysooriya et al., 2021). A separate flow is maintained for import containers. The consignee has the responsibility to clear the documentation process and the import container is picked by import truck (Muravev et al., 2019). ITT receiving and delivery time at gates depend on vessel calls of the outbound vessel of the transshipment containers.

The collaboration between container terminals connects the ITT operation within the same port (Negenborn, 2014). The mutual understanding among container terminals interconnects ITT operations as the processes are introduce in Figure 2 and Figure 3. Signing Mutual agreements is a widespread practice in international container ports. The truck usage has been predicted to reduce by 13% in 2030 by Port of Rotterdam Authority through an agreement that has been established internally. Optimizing rail operations through proper scheduling has been identified by Port of Rotterdam Authority to reduce truck movements (Negenborn, 2014).

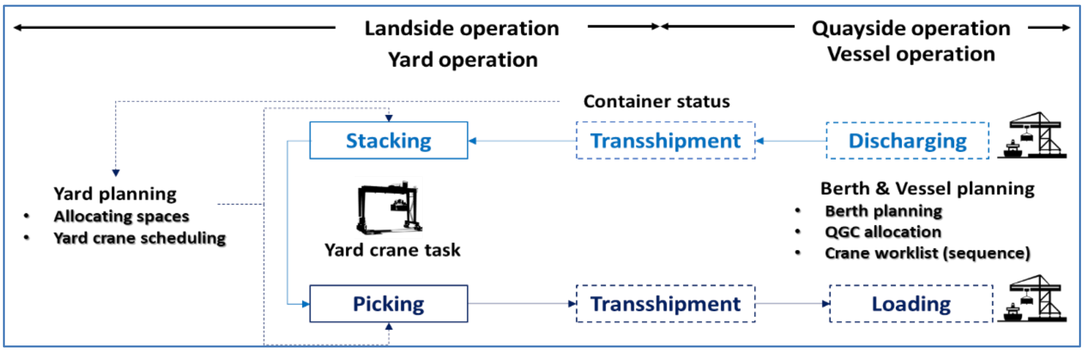


Figure 4: The transshipment processes (handling inside the same terminal)

The containers that are discharged and loaded within the same port can be specified as Transshipments (Güven & Eliiyi, 2018). The ITT operations are not overlapped with pure transshipment operations when the container is loaded and discharged within the same terminal (Güven & Eliiyi, 2018). The idle time of yard cranes can be reduced by optimizing the transit time of transshipment containers. (Cai et al., 2014).

The percentage on each operations type is varied from one container port to another container port. However, it is similar for terminals within the same port in most of the cases. Regional factors as well as the economic abilities of the country decide the trends of the container ports. For instance, the value of Chinese exports has been calculated as 25% of the global maritime trade. The port industry is extremely depended on the economy of China (UNCTAD, 2019). Transshipment operations are the most popular operations in hub ports. Hub ports that operate transshipment operations more than 70% from the total operations can be highlighted as port of Singapore, Algeciras, Salalah, Lianyungang, Malta, Kingston and Pelepas. This percentage is approximately varied between 50% to 70% in Port of Colombo, Hong Kong, Valencia and Piraeus (Notteboom et al., 2014). Port of Shanghai and Rotterdam port are operating transshipment cargo with a less percentage. It indicates their major operations are imports and exports.

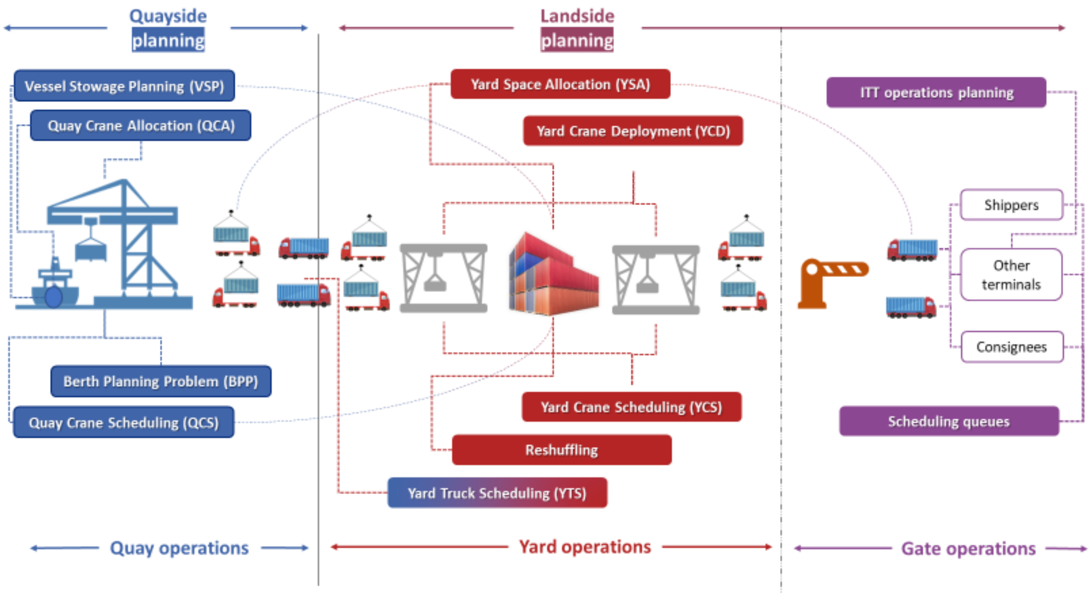


Figure 5: Planning functions at container terminals

Separate planning tasks are performed to function each operations process. Figure 5 explains how each planning function can be labeled under quayside and landside operations. Quayside planning (2.2.2) as well as landside planning (2.2.3) are discussed further.

2.2.2 Quayside planning

Quayside planning function and landside planning function have been identified as main focuses in container terminal planning as per the discussion so far (Jin et al., 2014). The vessels are operated at the quayside. Handling system plays a significant role in connecting each function. QGC is the elementary equipment that is operated at quayside. The types of QGCs can be identified as high profile QGC and low profile QGC (Bartošek & Marek, 2013). One of the main jobs that QCs perform is the discharging operation where the vessel is discharged. Quayside operation connects to internal terminal trucks, railroads, or SCs. Internal terminal trucks, railroads, or SCs are used to transport discharged containers to the yards. Containers that are temporary stacked at yard are transported by internal terminal trucks, railroads, or SCs for loading purpose. QGCs perform the loading operation once the container reaches quayside (Li et al., 2015). Berth Allocation Problem (BAP), Quay Crane Assignment (QCA), Quay Crane scheduling (QC scheduling), and the Vessel Stowage Planning (VSP) are the separate planning functions inside quayside function. It is crucial to integrate quayside and landside planning functions for a smooth operation (Kizilay & Eliiyi, 2020).

2.2.2.1 Berth Planning (Berth Allocation Problem - BAP)

The place where the vessel is anchored can be identifies as Berth. The land area that the vessel is operated, the berthing area is a limited resource (Abdel-Fattah et al., 2013). Therefore, it is crucial to optimize the berth area using advanced features of BAP. Berth schedule is displayed for every customer and other parties while it ensures the convenience of the direct customers of the terminal, shipping and feeder lines. Abdel-Fattah et al., (2013) explain that the long-term relationship between the terminals and shipping and feeder lines are maintained through agreements such Service Level Agreements (SLA). The BAP has investigated the waiting time for vessels, port attractiveness, utilization of resources, profits, and sustainability (Abdel-Fattah et al., 2013). Productivity, port efficiency, QC options are the factors that must be considered further in studies when berths are allocated (Carlo et al., 2014). Decision maker in BAP has a critical role since the BAP on top of other planning functions in the planning hierarchy (Castilla-Rodríguez et al., 2020).

BAP attributes are specified within four categories; Spatial, temporal, time for handling, and the measures of performances (Carlo et al., 2015). The berth characteristics are represented by spatial attributes. Temporal attributes are included by arrival time that is predicted and the availability of berths. Factors that are included such as moves of QGCs and YCs can be counted under handling time attributes. Further, performance measurement attributes represent waiting time of vessels and time that vessel operation is completed (Carlo et al., 2015).

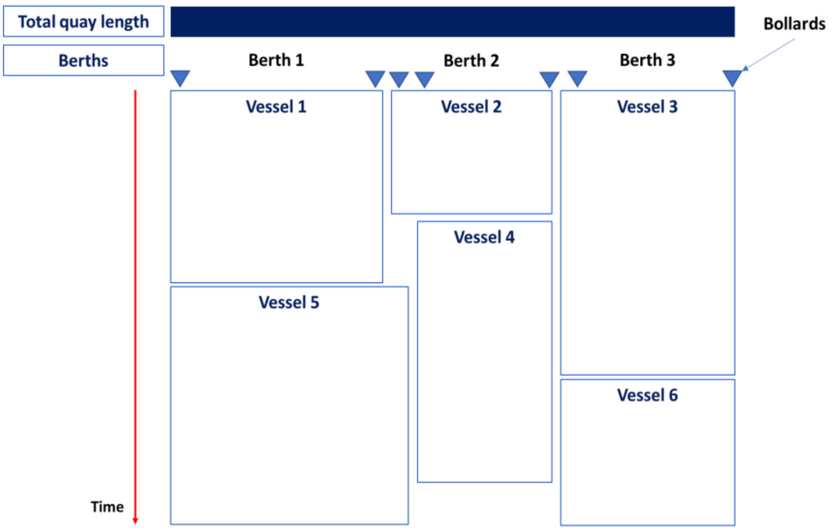


Figure 6: Berth planning function

Berth planner has the responsibility to understand the characteristics of the berth. As Figure 6 displays, the length of the berth is flexible while it is fixed for a certain period of time where it is specified as the time that the vessel remains at the berth. Length Overall that is well known as LOA of the ship decides the length that is needed for berth operation. The vessels are Bollards are tightened using bollards and ropes. Therefore, the bollards allocation is also a part of BAP. QGC jobs that must be operated in vessel operation defines the initial time that is taken for the operation. Berth occupancy percentage should be maintained at a high rate when the berth is optimized (Navis, 2014). Although handling time is calculated, a margin is added due to uncertainties (Navis, 2014).

Equation 1: Handling time for the vessel

Source: Navis, (2014)

$$Vessel\ handling\ time\ = \frac{Number\ of\ QC\ jobs}{Berth\ productivity} + \ Margin$$

In Equation 1, handling time for the vessel can be calculated using the number of QGC moves to be operated as well as the berth productivity. However, the issue rises since container slots that should be operated are not distributed equally along the vessel. Heavy number of moves must be completed in some bays. Therefore, the time that is initially calculated cannot defined as an accurate measure.

2.2.2.2 Quay Crane Assignment (QCA)

The QGC allocation on each vessel is identified in the QCA problem. As the first step, the optimal number of QGCs that can be employed in each vessel should be identified (Ursavas, 2014). BAP is adjusted on the characteristics of the container terminal. The time that the vessel is operated is initially identified using Equation 1. However, it does not promise to stop the operation within the calculated time. That is where the crane intensity is calculated where it suggests the optimal QC option for each vessel by identifying the effect of the heavy bays (Pacino, 2018).

Equation 2: Calculating the crane intensity

Source: Pacino, (2018)

$$Crane\ (QC) intensity = \frac{Move\ count\ of\ the\ longest\ crane\ (move\ count\ in\ the\ heaviest\ bay)}{Total\ move\ count}$$

In handling time calculation in Equation 1, the distribution of cargo is not considered. Because when that calculation is done, the planner does not know the exact handling positions of the vessel. Once the planner receives the exact distribution of positions, crane intensity can be calculated. The most efficient crane option for each vessel is calculated each vessel. Equation 2 displays how the crane intensity is calculated. It helps in identifying the most accurate vessel handling time when there is no additional bottlenecks such as crane breakdowns (Pacino, 2018). Then the QCA is performed on the identifying QC allocation through crane intensity.

2.2.2.3 Vessel Stowage Planning (VSP)

Central planner of the shipping line provides positions for stowage (Beens & Ursavas, 2016). Information that is needed for applying the loading plan is given through special instructions. Destination that the containers are unloaded and the weight of the containers are included in the stowage plan (Beens & Ursavas, 2016). This remarks the beginning of the integrating the vessel plan and the yard plan. Integrated planning is a broad area that is important to investigate in future studies according to Kizilay & Eliiyi, (2020). The cranes that are available in the yard perform stacking and picking operations that relate to the vessel operation. The vessel stowage planning process is identified as VSP. This can be performed once the QCA is completed since exact container is not compulsory to allocate cranes on bays. VSP can be altered due to several reasons. Then the VSP also effects in altering other planning functions as well according to Weerasinghe et al., (2022).

2.2.2.4 Quay Crane scheduling (QC scheduling)

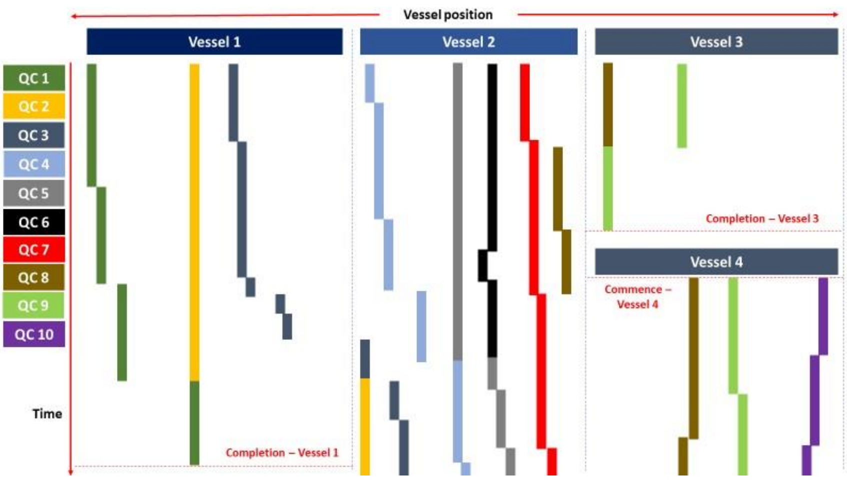


Figure 7: Vessel handling time (Navis, 2014)

The exact number of QCs that must be allocated for each vessel is identified with the time factor in QC scheduling problem. The exact crane bays that are suggested by vessel central planner is covered in QCA problem (Chen et al., 2012). Stability of the vessel is a key constraint that has been given the attention in previous studies (Al-Dhaheri et al., 2016). Minimizing the vessel handling and turnaround time is the main objective in QC scheduling problem. Figure 7 showcases an example view of the QC scheduling dashboard. An integrated grid of both the time that the operation takes as well as the vessel position are displayed through the dashboard. Similarly, a specific time frame is identified that a crane should work for each vessel. Once the cranes are specified exact containers are assigned that should be loaded into specific bays. (Chen et al., 2012). Directional QC scheduling and unidirectional QC scheduling problems have been investigated in previous studies (Chen & Bierlaire, 2017). Task, crane, interface, and performance measure are the key attributes that represent the QC scheduling problem.

2.2.3 Landside planning

Yard, gate and related tasks are represented by Landside operations. Yard positions must be allocated for containers on their operational perspective, export, import, and transshipment in yard planning. Yard planning is the most important part of Yard Management (YM) in tactical level decision process in container terminals (Zhen et al., 2016). Overall terminal efficiency is depended on yard operations while scarcity in yard space has a significant role. Even Port of Singapore, the busiest transshipment port in the world faces this scarcity problem (Jin et al., 2014). Frequent policy changes, demand on the consumption of energy, and pressure that is built on planners and operators are remarked as rising issues because of scarcity (Gerken et al., 2020). Yard area can be expanded in some cases while it does not fix in all the times. Therefore, expanding the planning function must be investigated (Kastner et al., 2020). YSA, YCD, and YC scheduling are highlighted as main tasks inside YM (Jin et al., 2014). Dynamic environment leads to complicate the YM in any terminal. Yard planning integrates with all the planning tasks inside quayside and gate operations as well as internal functions within YM. Recent studies have found that dynamic approaches higher capability than conventional trials (Görges & Freitag, 2020). Furthermore, YT has been investigated in many of the studies (Kizilay & Eliiyi, 2020).

Figure 5 shows that more than 50% of the published articles have been conducted inside yard operations.

2.2.3.1 Yard Space Allocation (YSA)

YSA identifies most convenient yard allocations for containers entering from gate end and quayside. Stacking positions are selected for operational types of inbound trucks that have been identified as imports, exports, transshipment with ITT containers (Güven & Eliiyi, 2014). Stacking policies lead the yard planner to take decisions on YSA. Stacking policies are included by specific guidelines that help the yard planner. Rate that changes the container positions, YC efficiency, and truck turnaround time can indicate the efficiency of previous studies emphasizes four stacking policies leveling, random, closest position and maximum remaining stack capacity.

Export and ITT receiving containers are stacked at the yard until their outbound vessel arrives. Import and ITT delivery containers are stacked in the yard until their outbound truck arrives. An example of a stacking policy can be identified as considering the next destination port of the export, ITT, or transshipment container. This is a grouping method (Fibrianto et al., 2020). The workload at a considered area should be considered before allocating spaces. It has been found that the workload-based yard planning method can reduce the vessel turnaround time (Fibrianto et al., 2020). Stack height is also an operational policy decision in a terminal (Zhen et al., 2016). Stacking policies can be adjustable with its capacity levels (Stahlbock & Voß, 2008). Two methods can be investigated in stacking. Reducing the idle time of YCs and reducing restacking are the areas that are discussed.

2.2.3.2 Yard Crane Scheduling (YC scheduling)

YC deployment (YCD) and YC scheduling are defined as the terms to indicate YC management (Guo & Huang, 2012). Numerous studies address the YC scheduling problem in various aspects. Stacking operations and picking operations are allocated to specific YCs in YC scheduling or YCD. Minimizing the average turnaround time of both the internal and external trucks is the fundamental objective of YC scheduling or YCD. YCs are a limited resource for a terminal, and it is an extremely significant issue for many terminals around the world. The optimal YC option for each yard block must be defined by integrating the operations.

2.2.3.3 Yard Truck Scheduling (YT scheduling)

The focus on YT scheduling is primarily intended for managing internal yard trucks and has little consideration on external trucks. Feeding the system in the yard end is the primary tasks of YT scheduling. YTs are not operated when SCs are employed in the operation. Common YC systems including RMG and RTG systems are needed YT systems that have efficient YM. Quayside and landside planning are integrated by YC scheduling (He et al., 2019). When empty truck trips occur or the trucks are idling, it leads to an inefficiency that must be investigated inside YM (Zhen et al., 2016). Railroads, and Automated Guided Vehicles (AGV) systems are used for YTs (Nellen et al., 2020). The idle trucks are fetched by the YT scheduling as the fundamental tasks. Kalmar smart path (Kalmar, 2013), and Navis prime route system (Navis, 2019) are some advanced systems in YT scheduling.

2.3 Review studies for identifying research gaps

Planning function (2.2.1), Quayside planning (2.2.2) and Landside planning (2.2.3) are explained the fundamentals of container terminal operations planning. The discussion is built using more than fifty studies. Identifying the most timely and critical research gaps improves the effectiveness of the study. The aim is to find the review articles under container terminal operations systematically to define research gaps more scientifically.

2.3.1 Types of review studies

Table 1 has been developed based on Grant & Booth (2009), Davarzani et al. (2016), and Perera et al. (2019) as well as the initial analysis of the study. Table 1 introduces a comparison of diverse ways of conducting review studies. Table 1 explains how the identified six different types of review studies can be positioned as critical review, systematic literature review, bibliometric analysis, overview/ literature overview, literature review, and review.

Most significant studies are highlighted in critical reviews through narrative analysis. Systematic search is proposed to find future directions in systematic literature reviews. Bibliometric analysis can be an initial analysis of review studies that reveal the quantity of literature, and trends in publications based on authors, affiliation, etc.

Overview/ Literature overview introduces a summary of literature through a broader perspective. A literature review introduces literature that comes under a certain defined scope. There is no structure or systematic way of doing a literature review while still it must be defined scientifically. Reviews are conducted from a broad perspective by looking from an umbrella view.

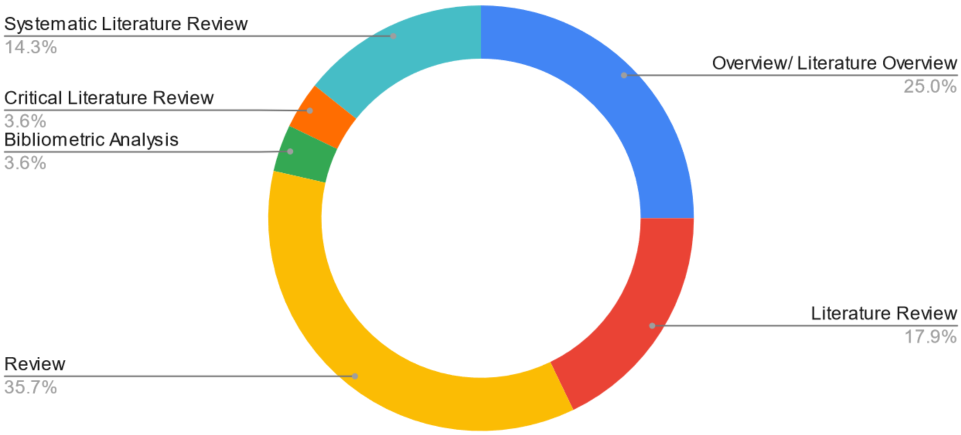


Figure 8: Types of review studies - Distribution

We find that only four systematic reviews have been published out of the twenty-seven identified review studies. Similarly, it highlights in Figure 8 that only 14.3% of the review studies follow a standard systematic process to conduct the review study under container terminal operations. More than 75% of the review studies are conducted as reviews, overviews or literature reviews. 7.2% of the review studies are conducted as critical literature reviews or bibliometric analyses which have a more specific way to be conducted.

Table 1: Types of review studies

Type of the review	*Characteristics*	*Synthesis*
Critical review	Literature is reviewed critically. Referring to the most significant studies in the field. Evaluating their degree of analysis and conceptual innovation	Most significant studies, narrative
Systematic literature review	Literature is searched systematically. Appraisals and syntheses of research evidence are derived systematically. Discoveries and recommendations for practice are defined under future directions,	Systematic search, future directions
Bibliometric analysis	A systematic review process based on the authors' perspective Information: annual counts, authors, institutes, etc. are defined Evaluating trends in publications	Quantity of literature, trends in publications
Overview/ Literature overview	There is no guarantee of a systematic process The literature overview refers only to scientific publications, but other related publications are also taken into consideration. A summary of the literature is presented.	Summary of literature, overview ideas
Literature review	There is no guarantee on the systematicity of the process followed. The literature is defined based on the authors' perspective of the field. The discussion is developed based on the pre-defined areas in the fields.	Literature review, defined areas
Review	It discusses a broad area. Papers considered the most significant are discussed critically. Umbrella views are discussed.	Umbrella view, broad perspective

Container terminal automation (Kon et al., 2020), machine learning applications (Filom et al., 2022), container terminal performance (Kurniawan et al., 2022) and classifying games in the container terminal logistics field (Nasution et al., 2022) are the key areas that systematic review studies cover.

2.3.2 A systematic process to identify review studies in container terminal operations

Review articles conclude research directions as per the practice. It helps to identify research gaps scientifically. Therefore, finding research gaps is followed a scientific and systematic process proposed by Perera et al., (2020), Perera et al., (2019) and Davarzani et al. (2016). The scientific process follows nine steps that are introduced in Phase 1 (PHASE 1 - OPTIMIZING CONTAINER TERMINAL OPERATIONS: A SYSTEMATIC REVIEW OF OPERATIONS RESEARCH APPLICATIONS

Review methodology and initial data analysis (3.1). As per the first step, Keyword Structure (KS) is proposed as it is displayed in Figure 9.

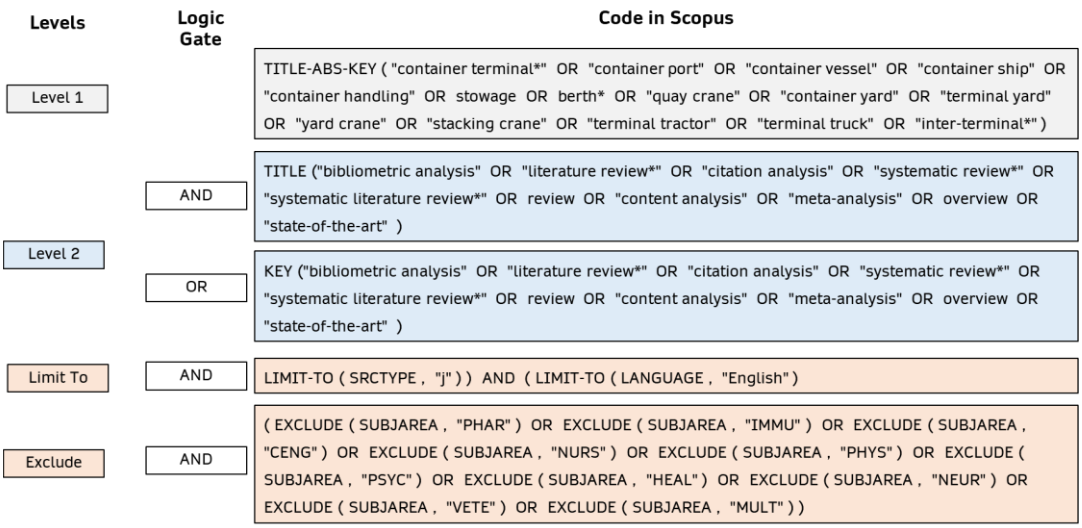


Figure 9: Keyword structure - Initial literature review

The KS for the initial stage includes two levels to identify the studies within the scope. The KS is tested using the Scopus database. This KS supports extracting relevant review studies from Scopus. Then the research gaps are identified with the direction of both the review studies and the literature review of the study. According to Perera et al., (2020), and Perera et al., (2019), Scopus is one of the well-reputed databases for research articles while the source is suggested for future research.

The scope for the initial literature review is defined as review studies under container terminal operations as in Figure 9. The next two steps are to limit the search result by removing papers, those come under irrelevant subject areas that have been published in the English language. Then the rest of the steps are followed that have been suggested in PHASE 1 - OPTIMIZING CONTAINER TERMINAL OPERATIONS: A SYSTEMATIC REVIEW OF OPERATIONS RESEARCH APPLICATIONS

Review methodology and initial data analysis (3.1). This extensive search is conducted using the Scopus database and we find that twenty-seven review studies are available as journal publications under the scope as at 24th of July 2022. We used the mechanism proposed in Equations 1, 2, 3 & 4 in Section 3.

2.3.3 Identify research directions through review studies

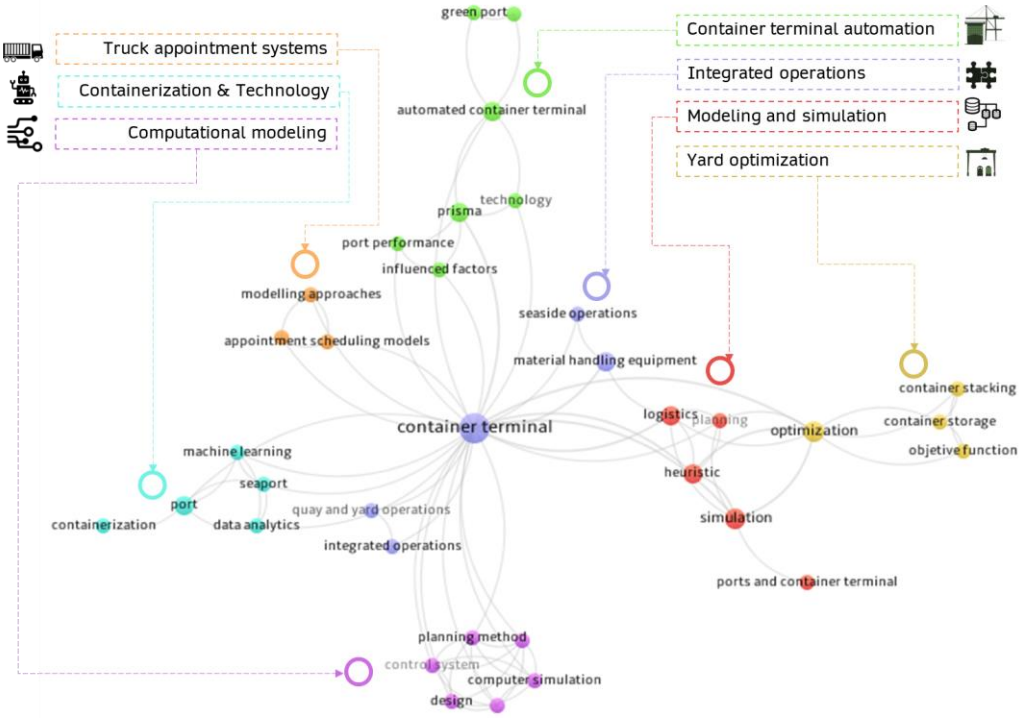


Figure 10: Identified clusters – Review studies under container terminal operations

Seven clusters are identified within these 27 studies: 1) Truck appointment systems, 2) Containerization and technology, 3) Computational modeling, 4)

Container terminal automation, 5) Integrated operations, 6) Modeling and simulation and 7) Yard optimization according to Figure 10. These clusters can be explained as follows.

The first cluster, Truck appointment systems represent the truck management inside container terminals. Islam, (2017) has conducted a review study on the empty truck trips problem at container terminals. The study discusses the importance of discussing supply chain collaboration for enhancing the maritime supply chain through optimizing empty truck trips. Islam, (2017) further claims utilizing empty truck trips can improve the transport capacity significantly. The cluster elaborates that the necessity of conducting research on the multi-modality ITT systems, and cooperation frameworks (Q Hu et al., 2019). Similarly, Hu et al., (2019) highlight the importance of applying quantitative methodologies for truck management studies through a critical literature review. Abdelmagid et al., (2021) introduce the latest comprehensive review of cluster 1 to evaluate the truck appointment scheduling problem. According to Abdelmagid et al., (2021) the impact of implementing information and communication technologies on the external truck appointment scheduling problem must be discussed further.

The second cluster, containerization and technology explain containerization, data analytics as well as machine learning with the evaluation of the cluster. Behera et al., (2000) conduct an overview on practices at marine container terminals of using management information systems in Asian and Australian regions. It encourages studies to observe whether the standardization of container location leads to higher productivity. Maloni & Jackson, (2005) discuss the North American container port capacity through a literature review. It proves that the first half of the decade starts from 2000, generates overviews that cover regional content.

Gharehgozli et al., (2016) explain that two areas can be introduced based on literature; 1) Innovative container terminal technologies and 2) New OR directions and models for existing research areas. Lau et al., (2017) focus on container shipping research since the 1960s conducting a bibliometric analysis. According to Lau et al., (2017), container shipping is one of the areas that is centralized into a few, weakly connected research battalions. Therefore, the importance of strengthening the network of co-authors has been highlighted for future research. Filom et al., (2022) evaluate applications of machine learning methods in port operations as per the most recent study in the cluster. However, it is the most recent systematic review of the overall scope as well.

Angeloudis & Bell, (2011) conduct the only review study that concentrates on the third cluster, computational modeling. Angeloudis & Bell, (2011) elaborate on how the ports in the Netherlands, Germany, Korea, and Italy have corporate into academic research in the domain. This is a specific review since the categorization has been introduced based on the implementation of the model.

Cluster four, container terminal automation is one of the most trending clusters according to our findings. It included port performance aspect in addition to the key focus of container terminal automation. Fazlollahtabar & Saidi-Mehrabad, (2015) conduct a review study evaluating methodologies to optimize Automated Guided Vehicle (AGV) scheduling and routing problems. AGVs are significantly contributed to the growth of container terminal automation over the years. The paper introduces specific research gaps related to manufacturing, distribution, transshipment, and transportation systems. Therefore, the study covers container terminal operations partially.

Kon et al., (2020) conduct a systematic review study covering the global trends of automated container terminals. The container terminal automation has increased the terminal efficiency in productivity, cost reduction and environmental sustainability as per the findings of the study (Kon et al., 2020). Berth planning is one of the areas that integrated the vessel owners, navigation systems and terminal operators. Applications of artificial intelligence in ship berthing are investigated in a recent review study by Imran et al., (2021). Artificial Neural Network (ANN) is proposed for future research for collision avoidance while completing ship berthing operations (Imran et al., 2021).

Further, a systematic review is conducted on factors influencing container terminal performance by Kurniawan et al., (2022). Improving the areas of operation time, container handling time, and quay crane productivity can enhance container terminal operations significantly (Kurniawan et al., 2022). Another aspect of review studies of container terminal operations is introduced as games in container terminal logistics field in a systematic review developed by Nasution et al., (2022). Games that represent container terminal operations can enhance the knowledge of the relevant field while existing games must be improved in future studies (Nasution et al., 2022).

Cluster five represents the overall operational aspect of container terminal operations. As Figure 10 explains that integrated operations, material handling equipment, quay and yard operations and seaside operations are included in cluster five. Blankmann & Klimbie, (1985) is the oldest study that is found under the scope. It covers the existing and planned transshipment facilities in container terminals as an overview. Vis & De Koster, (2003) updates the cluster by conducting the second overview of the cluster, Transshipment of containers at a container terminal. Therefore, the cluster starts by discussing the transshipment operations.

Zhang et al., (2008) conduct a review study on containership stowage planning. This stowage planning problem is an integrated discussion between the vessel operator and the terminal operator. The cluster is updated after 7 years, conducting a review study covering seaside operations by Carlo et al., (2015). However, the paper has a limit that reviews papers only between 2004 and 2012. Kizilay & Eliiyi, (2020) have conducted a comprehensive review covering quay crane scheduling, yard operations and integrations. The significant contribution of the study is the classification that explains all the aspects of quayside, landside and integrated operations. The importance of conducting integrated studies is highlighted as the main research gap (Damla Kizilay & Eliiyi, 2020). The most recent review study is conducted as a literature survey on berth allocation and quay crane assignment/scheduling problem. The paper guides how future research under uncertainty must be shaped. Proactive, reactive, and proactive/reactive are the three categories that are proposed for future research as key directions under the uncertainty factor (Rodrigues & Agra, 2022).

The sixth cluster, Modeling and simulation is a significant cluster with its contribution to the field. Steenken et al., (2004) contribute with one of the most contributions to the field of OR under container terminals operations. Stahlbock & Voß, (2007) have updated the previous study by introducing new research directions. There is no research is found that focuses on OR in container terminals as the pure scope of the study from 2007 onwards. However, Gharehgozli et al., (2016) conducted their study by focusing on new OR directions while discussing innovative container terminal technologies as their key focus. The cluster has been updated introducing the review study conducted by Dragović et al., (2017). The study reviews simulation modeling in ports and container terminals. The integrated solution must be prioritized as Dragović et al., (2017) highlight.

The seventh cluster discusses yard optimization as the key aspect. It directly deals with the modeling and simulation cluster. A literature review on objective functions for stacking containers is conducted by Jacomino et al., (2017). Minimizing unproductive movements of yard cranes and minimizing the cost of transportation of containers during stacking are introduced as two key objectives under yard optimization (Jacomino et al., 2017). Encouraging more research into and application of operations management techniques and tools is proposed by Lee & Song, (2017). Abdelshafie et al., (2022) conduct their review to identify and evaluate repositioning and optimal re-allocation of empty containers. Uncertainty, travel time, traffic congestion, and demand are suggested as factors to be considered in hybrid algorithms (Abdelshafie et al., 2022).

2.3.4 Evolution of review studies under container terminal operations

Figure 11 explains how the review studies of container terminals have evolved throughout the past years. First, the classified areas under clusters are identified based on the average publication year. The average publication year highlights how the areas appeared in the publication timeline. Areas under data analytics, green port, machine learning, port performance, yard management, appointment scheduling models, automated container terminals, integrated operations, quay and yard operations, truck appointment systems, container stacking, and container storage appeared in recent review studies between 2016 and 2022.

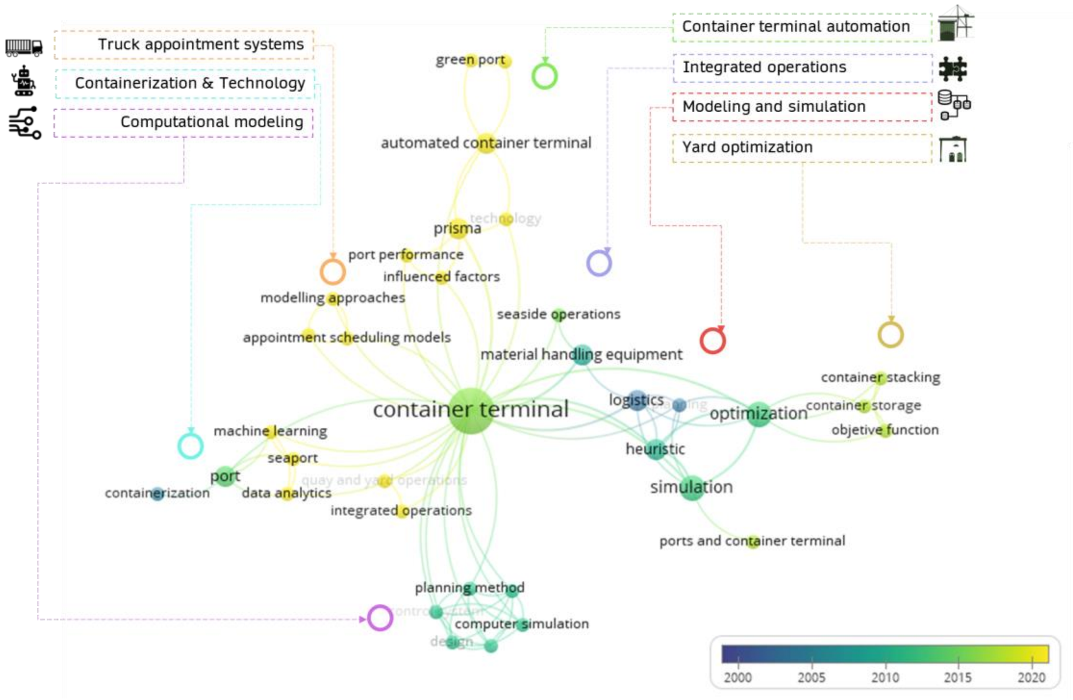


Figure 11: Evolution of identified clusters – Review studies under container terminal operations

Seaside operations, optimization, simulation, computer simulation, control system, numerical models, and planning methods are the areas that have been highlighted between 2010 – 2015. Material handling equipment, containerization, planning and logistics are the areas that received the average publication year which comes before 2010.

2.3.5 A research gap to develop a systematic review

Systematically driven mechanisms to classify clusters ensure replicability (Perera et al., 2019). A limited number of systematic reviews are identified in 2.3.1;

container terminal automation (Kon et al., 2020), machine learning applications (Filom et al., 2022), container terminal performance (Kurniawan et al., 2022) and classifying games in container terminal logistics field (Nasution et al., 2022). Significantly, three out of four systematic reviews are published in 2022. It signifies the need of publishing reviews through systematic processes to enhance scientific research has been noticed by authors very recently.

Further, Dragović et al., (2017) discuss simulation studies in their review study. Gharehgozli et al. (2016) have discussed OR applications in container terminals from the perspective of modern technologies and OR models. However, we find that no review studies have been conducted focusing purely on OR techniques after Stahlbock & Voß (2007) under the cluster of modeling and simulation in Figure 10. Therefore, we find that *"The area of operations research under container terminal optimization was not covered as the pure focus of any of the review studies after 2007*".

The review studies are followed to identify research gaps. However, there is a research gap is found to conduct a systematic review study when review studies are followed. Considering all the above research gaps, the following research objective is identified to plug this study. "*Identify the research trends in operations research context under container terminal operations planning using a systematic review process*" is the main objective of the first phase of the overall study. Once the systematic review on OR applications in container terminals is conducted following the above objective, specific research gaps are identified further. Phase two of the project is defined by considering the research gaps that are highlighted under the literature review (2) as well as the suggested systematic review (3).

3 PHASE 1 - OPTIMIZING CONTAINER TERMINAL OPERATIONS: A SYSTEMATIC REVIEW OF OPERATIONS RESEARCH APPLICATIONS

3.1 Review methodology and initial data analysis

The systematic process for the review study was identified after going through a number of systematic review studies published within the domain of transport and logistics (Davarzani et al., 2016); Perera et al., 2019). One of the most important aspects of systematic reviews is replicability (Lunin & Glock, 2021). Perera et al. (2020) and Davarzani et al. (2016) outline nine steps that can be identified: 1) Defining the Keyword Structure (KS), 2) Search in a selected database, 3) Narrowing down the result based on the subject area, 4) Use inclusion words to filter relevant publications, 5) Use exclusion words to filter out irrelevant publications, 6) Verification with relevant reference lists, 7) Finalize the selected studies for the analysis, 8) Conduct bibliometric analysis and 9) Generate the clusters and present trends in the scope.

Logic Gate	Levels	Code in Scopus
	Level 1	TITLE-ABS-KEY ("container terminal*" OR "container port" OR "container vessel" OR "container ship" OR "container handling" OR stowage OR berth* OR "quay crane" OR "container yard" OR "terminal yard" OR "yard crane" OR "stacking crane" OR "terminal tractor" OR "terminal truck" OR "inter-terminal*")
AND	Level 2	TITLE-ABS-KEY ("operations research" OR "operational research" OR simulation OR "linear progra*" OR "nonlinear progra*" OR "dynamic progra*" OR "integer progra*" OR "queuing theory" OR "transportation problem" OR "game theory" OR "markov chain" OR planning OR schedul* OR sequenc* OR reshuffl* OR deployment OR allocation OR routing OR assignment OR loading OR unloading OR discharging OR stack*)
AND	Limit to	LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")
AND	Excluding	EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "IMMU") OR EXCLUDE (SUBJAREA , "PHAR") OR EXCLUDE (SUBJAREA , "HEAL") OR EXCLUDE (SUBJAREA , "VETE") OR EXCLUDE (SUBJAREA , "NURS")

Figure 12 : Keyword Structure (KS)

Typically, defining keyword structure (KS) is the most critical part of a systematic review since it can decide the direction that systematic review takes. Nevertheless, it is not all about setting up some common words that yield a search result. It must contain the ability to include previous studies that are available in the defined database with error rate that is allowed (irrelevant papers are not captured and relevant papers are not excluded).

The KS should be improved in the sixth step which verifies the list of results if the studies that have been well-established in the domain are not included. The KS is defined as per Figure 12 after careful improvements. Moreover, the structure of the KS includes two levels 1) Container terminal operations and 2) OR techniques in container terminal planning tasks. The intersection of introduced levels can include the previously published studies in the scope is the key assumption. Scopus database is used for searching relevant papers using the defined KS as per the second step.

Then the search result is narrowed down to journal publications that are published in English. The third step is to narrow down the search result based on the subject area. It should be filtered carefully since some of the relevant papers might come under irrelevant subject areas. After sorting the search result based on the relevance in Scopus, irrelevant subject areas are identified as Medicine, Immunology and Microbiology, Pharmacology, Toxicology and Pharmaceutics, Health Professions, Veterinary, and Nursing. Once this step is completed, the Comma-Separated Values (CSV) file is ready to be downloaded from Scopus. The initial search result in Scopus was 4334 (Updated on 12th Aug 2022).

Inclusion keywords are used to recognize most relevant studies for the review. Studies that contain title or author keywords representing identified words from both the container terminal operations and operations research context are selected in the first phase of selection. Inclusion keywords are searched within the abstracts as well. The inclusion process captures 2257 papers in the initial stage. In addition to that, 2029 papers were identified to be eliminated using excluding keywords. A manual process was used to identify papers when those were captured by both the excluding and including criteria. At this time, 62 papers are selected to be included while 336 papers were eliminated manually after carefully going through the abstracts of each study. Ultimately, 1631 papers were identified which satisfy the inclusion criteria.

3.2 Bibliometric analysis

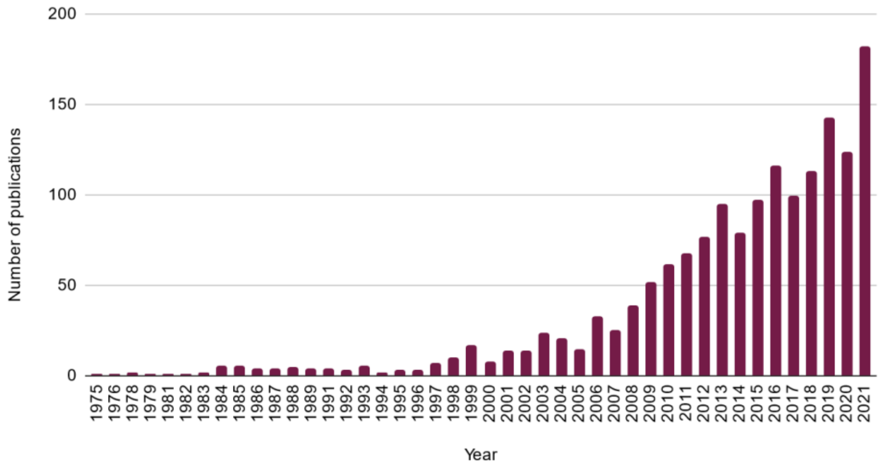


Figure 13: Number of publications by year

We conduct a bibliometric analysis after defining the exact paper pool which includes 1631 studies. Figure 13 indicates how the studies have been published on an annual basis until 2021 highlighting growing interest on the field.

The growth rate of 45% per annum is surpassed within our Scope by recording 11.16% number of studies in 2021. Less than 100 papers appear per annum before 2016. Table 2 displays how publication outlets are ranked based on the number of journal articles published. European Journal of Operational Research is leading the Table 2 while Transportation Research Part E: Logistics and Transportation Review is in second place with a margin of four articles. Computers and Industrial Engineering is in the third place. “Maritime Economics” and “Maritime Policy and Management” which have the full focus on Maritime Transportation are in fourth and sixth places respectively while OR Spectrum is in the 5th position.

It clearly indicates, most of the publications that focus on operations research applications in container terminal operations are published in outlets that bear a key focus of optimization through operations research. This also implies that domain specific journals should encourage more OR based publications in their journals.

Table 2: Publication outlets

Rank	Journal	No of Studies
1	*European Journal of Operational Research*	83
2	*Transportation Research Part E: Logistics and Transportation Review*	77
3	*Computers and Industrial Engineering*	69
4	*Maritime Economics and Logistics*	54
5	*OR Spectrum*	45
6	*Maritime Policy and Management*	41
7	*Transportation Research Part B: Methodological*	37
8	*Flexible Services and Manufacturing Journal*	33
9	*Transportation Science*	24
9	*Advanced Engineering Informatics*	24

Table 3: Contribution of the authors

Rank	Author	Institute	No of Studies
1	Kim K.H.	Pusan National University, South Korea	49
2	Zhen L.	Shanghai University, Shanghai	24
3	Voß S.	University of Hamburg, Hamburg, Germany	22
4	Yang Z.	Dalian Maritime University, Dalian, China	19
4	Lee D.-H.	National University of Singapore, Singapore	19
4	Zeng Q.	Dalian Maritime University, Dalian, China	19
7	Wang S.	Hong Kong Polytechnic University	18
8	Diabat A.	New York University Abu Dhabi, UAE	15
9	Boysen N.	University of Jena, Jena, Germany	13
10	Huynh N.	University of South Carolina, United States	12
10	Petering M.E.H.	University of Wisconsin, Milwaukee, United States	12

China, United States, South Korea, Singapore, Germany, Hong Kong and Italy are the main contributors towards research on container terminal operations optimization according to our analysis.

Then the authors' contribution is evaluated based on the number of publications that they have contributed. K.H. Kim of Pusan National University, South Korea is the top author having contributed to 49 publications within the defined context. L. Zhen of Shanghai University, Shanghai takes second place on the list. The third place of the list is taken by S. Voß of University of Hamburg, Hamburg, Germany. The author list which displays the top 10 positions in the defined context is shown in

Table 3.

Shanghai Maritime University, China is the leading institute which produced more than 150 publications within operations research context in container terminals. The National University of Singapore is second on the list with 83 publications. The third place is taken by Dalian Maritime University, China. Pusan National University, Busan, South Korea, and Hong Kong Polytechnic University take fourth and fifth places respectively. The University of Genova is the only institute that secured a place within the top 10 from outside Asia as illustrated by Table 4.

Table 4: Top 20 institutes

Rank	Institution	Location	No of Studies
1	Shanghai Maritime University	Shanghai, China	152
2	National University of Singapore	Singapore	83
3	Dalian Maritime University	Dalian, China	76
4	Pusan National University	Busan, South Korea	65
5	Hong Kong Polytechnic University	Kowloon, Hong Kong	50
6	Shanghai University	Shanghai, China	43
7	Tongji University	Shanghai, China	39
8	Shanghai Jiao Tong University	Shanghai, China	38
9	Dalian University of Technology	Dalian, China	30
10	Tsinghua University	Beijing, China	26
10	University of Genova	Genova, Italy	26
12	University of Hamburg	Hamburg, Germany	23
12	Beijing Jiaotong University	Beijing, China	23
12	Delft University of Technology	Delft, Netherlands	23
12	Nanyang Technological University	Singapore	23
12	University of Calabria	Calabria, Italy	23
17	Wuhan University of Technology	Wuhan, China	21
18	Technical University of Denmark	Lyngby, Denmark	20
18	Islamic Azad University	Tehran, Iran	20
20	Erasmus University	Rotterdam, Netherlands	19
20	University of Antwerp	Antwerp, Belgium	19
20	Donghua University	Shanghai, China	19

3.3 Analysis

Analysis consists with two subsections. OR applications and optimization in container terminal planning is discussed first (3.3.1). Then the identified research clusters will be discussed (3.3.2).

3.3.1 OR applications and optimization in container terminal planning

Quayside and landside are the key areas in container terminal operations (2.2.2 and 2.2.3). However, 14.8% of the studies have been conducted covering overall aspects of container terminal operations. Most of the papers in the category of "overall" including Li et al. (2021); Mi et al. (2021) and Lu (2021) have been conducted on aspects focusing on automation and scheduling problem. These papers focus on the overall container terminal panning function without focusing silos. Silberholz, Golden, and Baker (1991); Beškovnik (2008); and Sislioglu, Celik, and Ozkaynak (2019) contribute to how the productivity of container terminals can be standardized. Luna et al. (2018) discuss how to improve the handling efficiency at container terminals within the context of the overall operation. Seth and Feng (2020) claim that operational planning activities must be considered and interconnected with investments on container ports.

85.2% of studies have focused on exact planning function/ functions inside container terminal operations. Figure 14 explains how these studies (85.2%) have been distributed within different planning functions. Quayside planning attracts most of the studies which are 53.27% of the articles that focus on planning function/ functions as Figure 14 shows. BAP attracts 49.94% of the studies out of studies that focus on quayside planning function. Golias et al. (2009) highlight the importance of optimizing vessel arrivals by proposing berth allocation strategies.

Simulation modeling of ship-berth link with priority service (Dragović et al. 2005), vessel berthing and speed optimization policies (Alvarez et al., 2010), bi-objective berth allocation formulation (Golias 2011; Zeng, Feng, and Chen 2017) and carbon-footprint minimization objectives through integrated approaches (Karakas et al., 2021) can be introduced as the core areas that are discussed within BAP. The evolution of BAP can be revealed through understanding how the article titles have been introduced. The basic BAP has been discussed before 2010 while it moves toward an integrated problem within the decade from 2010 – 2020.

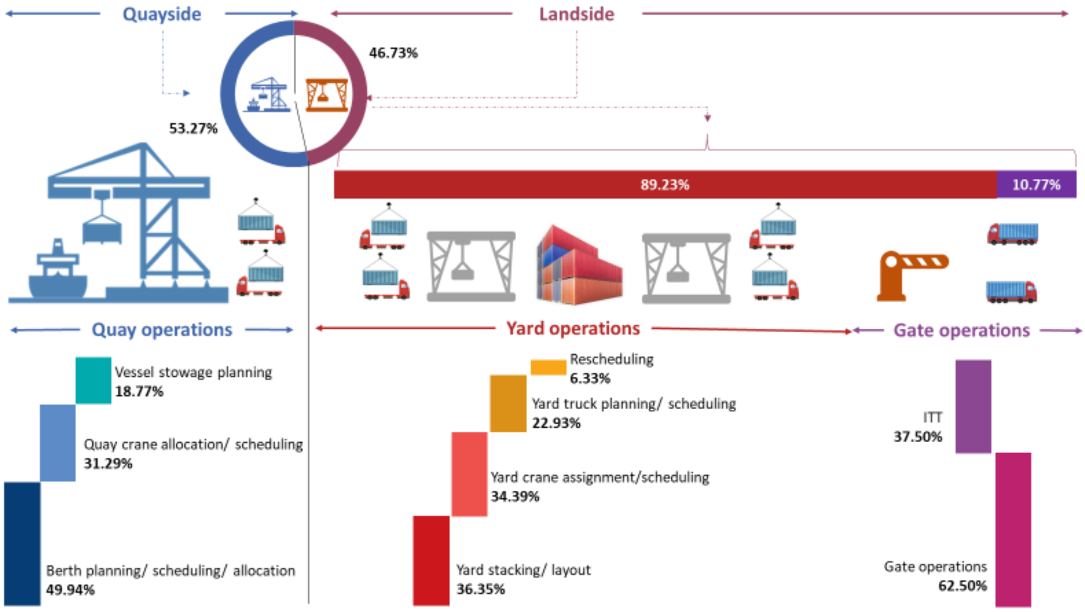


Figure 14 : Distribution of studies within planning functions

Quay crane allocation/ scheduling problem attracts 31.29% of articles from quayside studies. The area of QCA/ QCS appears in various aspects within operations research techniques. Bierwirth and Meisel (2010) have conducted a survey on berth allocation and quay crane scheduling problems. Focuses on loading and unloading operations in container terminals (Li and Vairaktarakis 2004), time windows (Kaveshgar & Huynh, 2015a), and stability considerations (Ursavas 2017) are highlighted in QCA/ QCS problems. Evaluation of available QCA/ QCS methods (Sun et al., 2021), integrated quay crane assignment and scheduling problem (Safaeian et al., 2021), integration of quay operations with yard operations (Kong et al., 2021) and sustainable approaches (Voß, and Song 2022) are few of the key areas that have been highlighted for conducting future research.

18.77% of the quayside studies have focused on VSP. VSP is a complex area where both the vessel operator's perspective and the terminal operator's perspective appear together. Shields (1984) investigates the VSP for the first time as a study that focuses on VSP as a separate area for the first time according to the database (3). Decision support system for VSP (Saginaw and Perakis 1989), principles of combinatorial optimization applied to VSP (Wilson & Roach, 1999), master bay plan problem (Ambrosino et al., 2004), constraint programming model for fast optimal VSP (Delgado et al., 2012), and heuristics related applications (Ding and Chou 2015) are the highlighted areas under VSP. Applying expert knowledge (Chou & Fang, 2021), benchmarking heuristics applications under VSP (Larsen & Pacino, 2021), and minimizing over stowage in master bay plans (Chao & Lin, 2021) are some of the areas that have been covered in recent studies.

Landside planning attracts 46.73% of the studies that focus on planning function/ functions as Figure 14 shows. Yard operations (89.23%) and gate operations (10.77%) are the key contributors within the landside. YSP and yard layout problems have received the highest contribution from authors which is around 36.35% out of landside studies. Focusing on inbound/ outbound categories of containers (Ting et al., 2010), minimizing dwell time (Moini et al., 2012), and integrated yard management (Karakas et al., 2021) are the areas that have been highlighted by the literature. Dynamic stacking problems (Gunawardhana et al., 2021), and integrated scheduling in automated operations (Zhuang et al., 2022) are trending areas within yard management.

Yard crane assignment/scheduling is the next focus of the authors in past studies. We found that YCS has attention on the landside which is much similar to QSC is focused within the quayside. Yard crane deployment (Laik & Hadjiconstantnou, 2008), and simulation and optimization (Legato et al., 2009) are some key areas that are highlighted in the literature. Reducing carbon emission (Ding et al. 2021) and collaborative and hybrid approaches (Hsu, Tai, et al., 2021) can be introduced as some recent trends in the area. YTS is one of the main contributors to integrated planning

(Figure 14). It connects with both the quayside and landside directly while 22.93% of landside studies have focused on YTS. YTS highlighted integrated scheduling of YTS and YCS (Cao et al. 2010) and multi-objective optimization (Homayouni & Tang, 2013) in the literature. Highlighting automated operations is one of the key focuses within YTS (Zhuang et al., 2022).

ITT operations (37.50%) and external truck management including overall gate operations functions (62.50%) are the main focuses within container terminal gate operations. The discussion that is built on truck appointment systems at gates is highlighted as the main focus within gate operations over the past decade (Zhao and Goodchild 2013; Li et al. 2022). Reducing the gas emissions at gates is a trending area within the gate operations function (Wasesa et al., 2021). ITT operations are incredibly important since it encourages inter-terminal collaboration. Introducing optimization techniques for encouraging collaborations is highlighted (T N Adi, Iskandar, & Bae, 2020). Simple optimization approaches to break the barriers between terminals are highlighted (Jin and Kim 2018).

3.3.2 Research cluster analysis

The next step is to generate research clusters to underscore the connectivity between countries and keywords and their evolution. The following equations have been used in the network analysis software that is suggested by the literature (Davarzani et al., 2016; Perera et al., 2019). These equations have been developed by Van Eck & Waltman (2014). According to Van Eck & Waltman (2014), association strength normalization constructs a normalized network in which the weight of the edge between nodes i and j is given by

Equation 3: The association strength normalization

$$s_{ij} = \frac{2ma_{ij}}{k_i k_j}$$

Equation 4: The total weight of all edges in the network

$$k_i = \sum_j a_{ij} \text{ and } m = \frac{1}{2}\sum_i k_i$$

Equation 5: VOS mapping technique - minimization function

$$V(x_1, \dots, x_n) = \frac{1}{2}\sum_{i<j} s_{ij} \left\|X_i - X_j\right\|^2 \text{ and } \frac{2}{n(n-1)}\sum_{i<j} \left\|X_i - X_j\right\| = 1$$

Equation 6: VOS clustering technique - maximization function

$$V(c_1, \dots, c_n) = \sum_{i<j} \delta(c_i, c_j)(s_{ij} - \gamma)$$

Where,

a_{ij}	The weight of the edge between nodes *i* and *j*. a_{ij}= 0 if there is no edge between the two nodes.
k_i	The total weight of all edges of node *i*
k_j	The total weight of all edges of node *j*
m	The total weight of all edges in the network.
n	The number of nodes in the network
x_i	The location of node *i* in a two-dimensional space
$\|\|x_i - x_j\|\|$	The Euclidean distances between nodes *i* and *j*
c_1	The cluster to which node *i* is assigned
$\delta(c_i, c_j)$	A function that equals 1 if c_i = c_j and 0 otherwise
γ	A resolution parameter that determines the level of detail of the clustering

Author keywords that are included in the selected studies are contributed to generate cluster graphs following Equation 3, Equation 4, Equation 5, and Equation 6 where keywords appear more than or equal to 8 times in literature. Five main research clusters are identified by analyzing the author keywords of the papers. These are defined as: 1. Simulating container terminal operations, 2. Scheduling operations and automating terminals, 3. Optimizing the quayside operations, 4. Integrated operations in container terminals and 5. Container transportation, after careful scrutiny of the papers under each cluster. The following subsections provide a detailed description for each cluster while highlighting fertile soil for future research

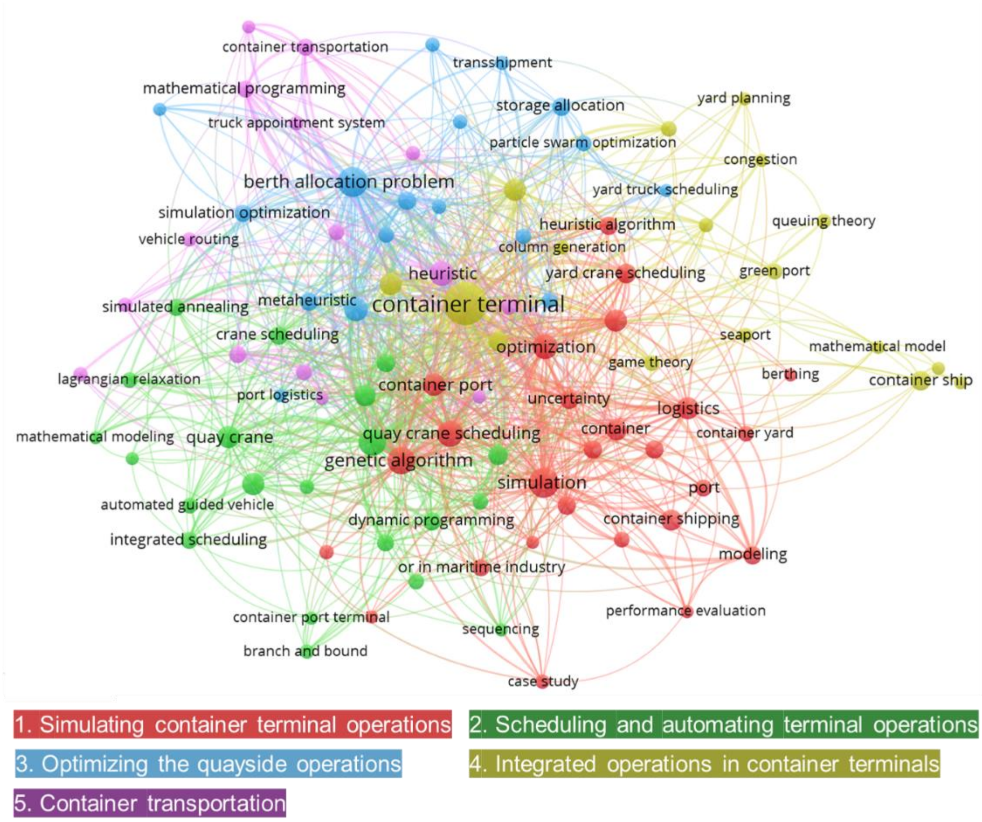


Figure 15 : Research clusters

3.3.2.1 Cluster 1 - Simulating container terminal operations

3.3.2.1.1 Simulating container terminal operations and its evolution

Simulating container terminal operations is the first cluster in which more than 10 papers per annum are published while the cluster maintains this count since 2003. Chung et al. (1988) have conducted a simulation analysis based on container handling. Raman & Ramkumar (1988) have focused on the waiting time of ships and berth occupancy in ports in their simulation model. Rego & Roucairol (1995) have introduced a dynamic multi-terminal truck dispatching problem as a tabu search-based simulation model. Kim & Kim (1999) lead to a new scope in the literature that discusses the segregating space allocation models for container inventories in port container terminals. One of the key strands that is observed is the focus on overall operations by introducing a simulation model before the 21st century.

After the year 2000, most of the studies have focused on very specific areas that can be introduced within well-defined scopes. Uesugi et al. (2001) discussed the scheduling problem in vehicle routing under the constraint of the limited number of berths. It highlights that the scopes turn into more specified problems from a broader perspective. This can be illustrated through examples. Nishimura et al. (2001) have conducted their study on berth allocation planning in the public berth system using genetic algorithms. Authors also focus on specific methodologies to specify their studies since the scoping does not focus on a specific function always. Steenken et al. (2004) discuss the OR-based simulation techniques in container terminals in their review study. Simulation models have appeared within all the planning functions. Quayside planning (Buhrkal et al., 2011; Shang et al., 2016), yard planning (He et al., 2010; Karakas, Kirmizi, and Kocaoglu 2021), and gate operations planning (Chen et al., 2013) have been discussed under simulating container terminal operations cluster.

3.3.2.1.2 Trending methodologies: Simulating container terminal operations

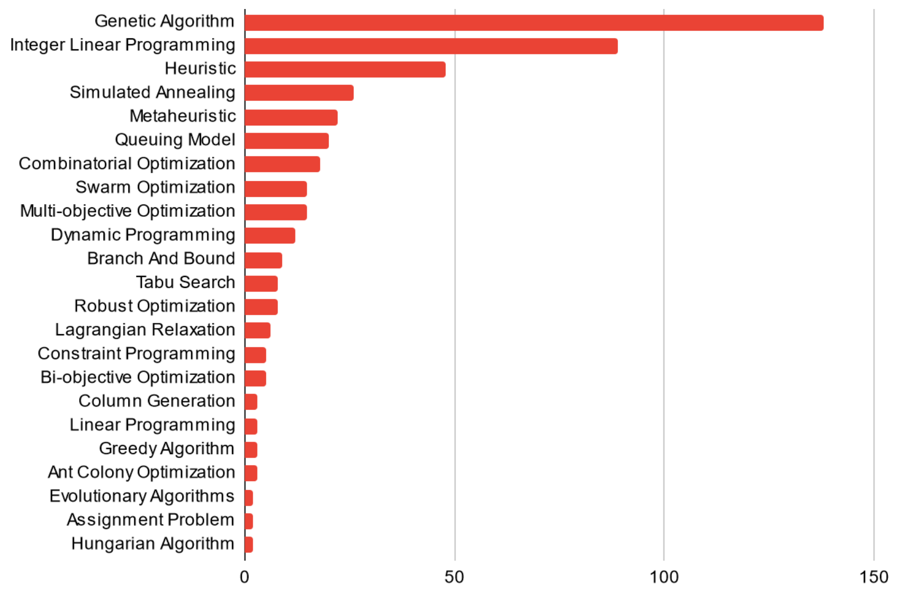


Figure 16: OR applications - Simulating container terminal operations

Genetic Algorithms (GA), integer linear programming, and heuristics are the methods that have been frequently used under this cluster (Figure 16). GA has been used across an enormous range of operations in container terminal planning. QCS (D.-H. Lee et al., 2008), BAP (M M Golias, Boile, et al., 2009), Integrating BAP and QCA (Chang et al., 2010), YCS (He et al., 2010) are conducted using GA based frameworks. Integer linear programming has been used within the areas of discrete BAP (Cordeau et al., 2005), integrated BAP and QCA (Liu, 2020; Iris et al., 2015), and container stowage slot planning problem (Parreño et al., 2016). Heuristics are applied in various ways to optimize container terminal operations (Monaco et al., 2014). Other than these trending methods, simulated annealing, metaheuristic, queuing model, combinatorial optimization, swarm optimization, multi-objective optimization, and dynamic programming are the methodologies that are applied in at least 10 studies or more.

Authors are trying to use more than one method to eliminate limitations in studies. Kastner et al. (2021) propose a simulation model using meta-heuristics, structured parzen estimator, Bayesian optimization, simulated annealing, and random search guide. Considering the constraints from integrated points in the operations is one of the key limitations that the authors are facing in building simulation models (Chamchang & Niyomdecha, 2021). Similarly, implementing proposed simulation models into practice is another challenging area. Chargui, Zouadi, Fallahi, et al. (2021) state this challenge in implementing a MILP model with the objective to minimize a normalized weighted sum of the mean absolute deviation of operators working hours and the total traveled distance by operators between assigned QCs.

Robust optimization, impact on maritime transport, uncertainty, stowage planning, and liner shipping can be introduced as trending research directions for conducting more studies under cluster 1. Robust optimization is frequently used to optimize quayside operations. Impact on maritime transport is a timely area since it provides directions to survive the industry with simulations to predict the impact. Stowage planning is also critical since it connects both the container terminal and the vessel operator. It must meet the requirement of the vessel operator to cater for upcoming ports of the voyage. Dynamic techniques can be introduced similarly when conducting simulations under the dynamic stacking problem (Gunawardhana et al., 2021). Traffic integrated yard allocation problem (C. Zhou et al., 2021), efficient layouts for automated container terminals (X. Li et al., 2021) and simulating integrated handling systems (Sha et al., 2021) can be suggested for future studies.

3.3.2.2 Cluster 2 - Scheduling operations and automating terminals

3.3.2.2.1 Scheduling operations and automating terminals and its evolution

Two areas, namely scheduling operations and automating terminals come under one cluster in the analysis. Eleven peer-reviewed journal articles that discuss scheduling automated operations, including Gharehgozli et al. (2021), Xu, et al. (2021), Li et al. (2021) and Tan et al. (2021) have been published within the year 2021. This trend of proposing models for scheduling automated container terminals explains why scheduling operations and automating container terminals appear under one cluster.

3.3.2.2.2 Scheduling operations

Scheduling operations is a trending topic according to the analysis of the study. This highlights the importance of conducting studies in scheduling operations. Scheduling operations are needed for all the planning tasks (Weerasinghe et al., 2022). Both QCS (Unsal & Oguz, 2013) and YCS (He et al., 2010), and truck scheduling problem (Cao et al., 2010) are being solved using OR applications. Sequencing operations is also really critical since it can affect container terminal efficiency directly (Vis & Carlo, 2010). Similar to observation under simulating container terminal operations cluster GA, integer linear programming and heuristics are the methods that have been frequently used in the second cluster as well (Feng Chu et al., 2019).

3.3.2.2.3 Automating container terminals

Nabeshima et al. (1978) have begun a discussion on automated container terminals. Chen et al. (2004) have conducted a study discussing automating port operations. Similarly, a study has been conducted on simulation-based performance evaluation of transport vehicles at automated container terminals by Yang et al. (2004).

According to Notteboom et al. (2022) three stages of terminal automation are defined: 1) Adoption, 2) Diffusion and 3) Maturity. As per their study, yard management automation would achieve a level of maturity when the decade of 2010 – 2020 ends. Notteboom et al. (2022) further argue that automating gate operations and tracking tasks come to the maturity level from the level of diffusion while yard cranes and quay cranes remain at initial stages of automation. This shows the importance of adjusting the planning function towards automating operations. Automated guided vehicles are the most popular area within automated container terminal optimization (Lu & Wang, 2019).

3.3.2.2.4 Trending methodologies: Scheduling operations and automating terminals

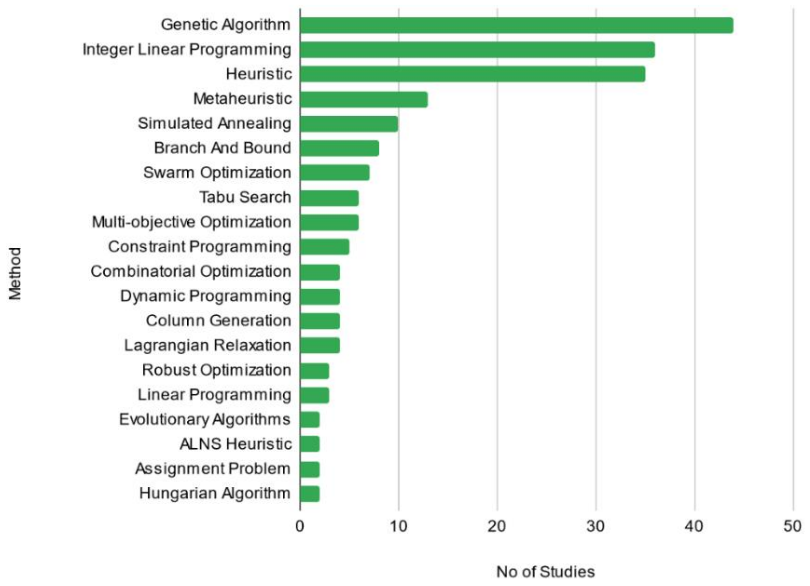


Figure 17: OR applications - Scheduling operations and automating terminals

BAP (Hansen et al., 2008), YCS (Ren, 2012), and sequence planning of quayside operations (Lu et al., 2013) are some areas where GA has been applied (Figure 17). Automated stacking cranes (Dell et al., 2009), assignment of storage locations (Wan et al., 2009), integrated BAP, QCA, and QCS (Agra & Oliveira, 2018), block relocation problem (Lu et al., 2020), and rescheduling strategy for BAP (Kim et al., 2021) are the key areas that integer linear programming has been applied. Heuristics are being applied with a similar frequency with integer linear programming in this cluster. BAP with a limited quay capacity (Imai et al., 2008), YSA (Wan et al., 2009) and stowage problem (Fazi, 2019) are the identified key areas that heuristics have been applied in various ways. Metaheuristic and Simulated Annealing are the techniques that are being applied at least 10 times or more in cluster 2.

The models should be updated when the industry practices are being changed. Gharehgozli et al. (2021) argue that the practice of deploying single automated stacking cranes (ASC) is changed into deploying more than one crane to improve efficiency while improving their MILP model. Chen & Zeng (2021) prove that MILP can be used to evaluate green ports since sustainable operations are being demanded. MILP can further address to mitigate the limitation of unidirectional movement of the quay cranes according to Safaeian et al. (2021).

Cluster 2: Scheduling operations and automating terminals, is heading to the areas of mathematical modeling, integrated scheduling, automated container terminals, Lagrangian relaxation, combinatorial optimization, mixed, integer programming, simulated annealing, dynamic programming, and automated guided vehicles. Gunawardhana et al. (2021) argue that container terminals are demanding dynamic scheduling and stacking tools to optimize their operation while our study reinforces the same finding. According to Notteboom et al. (2022) dynamics under integration between different stages: 1) Adoption, 2) Diffusion and 3) Maturity of automation should be considered when future studies are conducted within the scope of automating container terminals.

3.3.2.3 Cluster 3 - Optimizing the quayside operations

3.3.2.3.1 Optimizing the quayside operations and its evolution

Quay area includes a few critical planning tasks 1) Berth Allocation Problem (BAP), 2) Quay Crane Allocation (QCA), 3) Quay Crane Scheduling (QCS), 4) Vessel Stowage Planning (VSP). These areas are being discussed in other clusters as well.

However, quayside operations have a freestanding focus within optimizing container terminal planning according to Figure 18.

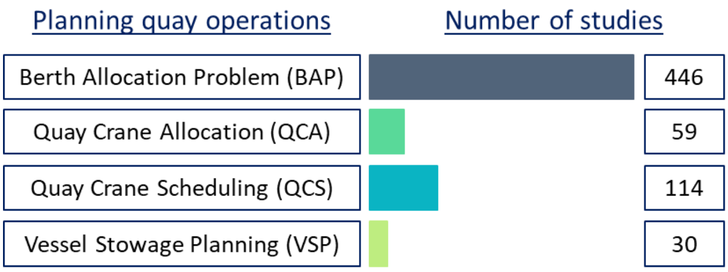


Figure 18: Quayside operations planning studies

As Figure 18 clearly indicates BAP or BPP (Berth Planning Problem) is the topic that is investigated with the highest frequency. Studies on QCA and QCS have been conducted as the next frequent topics in the list while the least focus is on VSP. According to Weerasinghe et al. (2022) constraints from both sides 1) Terminal operator and 2) Vessel operator are considered through VSP. Therefore, it is critical to solve VSP as an integrated problem since the vessel operator considers it for the whole voyage.

3.3.2.3.2 Trending methodologies: Optimizing the quayside operations

Figure 19 shows that GA is the method that is used as the most. This echoes the findings of the previously introduced clusters on simulating container terminal operations and scheduling operations and automating terminals. Integrating BAP and QCA (Zhang et al., 2010) and QCS (Chang et al., 2010), VSP (Dubrovsky et al., 2002), and 3D VSP (Azevedo et al., 2018) have been modeled using GA-based algorithms. QCS (D.-H. Lee et al., 2008) and loading sequence and rehandling strategies for multi-quay crane operations (Ji et al., 2015) have been addressed using heuristic algorithms. Metaheuristic, integer linear programming (Liu et al., 2016), simulated annealing, and combinatorial optimization are the methods that have been modeled as the next frequent methods.

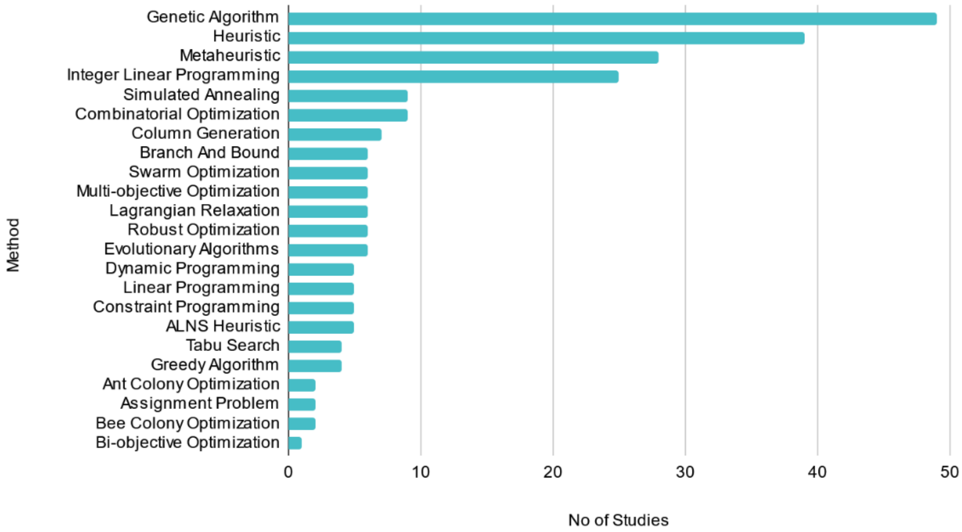


Figure 19: OR applications - Optimizing the quayside operations

Uncertainty is one of the key challenges that is faced by the berth planners. It is difficult to reschedule berths due to the limited number of berths. The limitation of the berth is the barrier that is discussed by most of the studies (Fernández & Munoz-Marquez, 2022). Kim et al. (2021) argue that rescheduling strategies for berth planning in container terminals can be proposed using MILP. It is worth investigating the altering nature of the berth planning through MILP in future studies. Worker performance variability is another area that is challenging to model. Chargui, Zouadi, El Fallahi, et al. (2021) argue that heuristics and variable neighborhood search can investigate the limitations in worker performance variability.

Cluster 3 shows particle swarm optimization, optimal fuel consumption, applications in meta-heuristic, simulation optimization, dynamic berth, and quay crane scheduling as trending research directions. More integrated studies are required to support a smooth operation between quayside and landside. An assortment of studies can be found under integrated berth planning although the domain demands more integrated studies between functions. Studies on automations are required to showcase effective mechanism of handling automated equipment. Gharehgozli et al. (2021) highlight the ability to apply OR techniques to optimize automated operations further. Focus on

Automated Guided Vehicles (AGVs) is trending within this scope. However still studies that guide terminal operations to synchronize the plan with all tasks are an urgent research gap that needs to be addressed.

3.3.2.4 Cluster 4 - Integrated operations in container terminals

3.3.2.4.1 Integrated operations in container terminals and its evolution

The decade starting from 2011 onwards mainly focuses on integrated problems. Kizilay & Eliiyi (2021) evaluate more than 200 preceding studies (2011–2020) and find that the percentage of studies focusing on the integrated perspective is less than 15%. Integration has been explained in various ways in literature (Weerasinghe et al., 2022). Integration is the application side of Terminal Operating System (TOS) in seaport terminal planning as per the view of Weerasinghe et al., (2022). However, most of the studies introduce integration as connecting two or more planning functions. We find only 6.76% of the studies have had an integrated focus. Weerasinghe et al., (2022) claim, that 69% of the integrated studies are related to YTS. QCS and YCS appear at 67% and 64% respectively within integrated problems.

3.3.2.4.2 Trending methodologies: Integrated operations in container terminal

Again, GA, Integer linear programming, and heuristics are the three main methods that were used in integrated operations in container terminals cluster as well (Figure 20). Integrating scheduling loading operations in container terminals (Zeng & Yang, 2009), integrating BAP and QCA (Chang et al., 2010; Diabat & Theodorou, 2014; Kaveshgar & Huynh, 2015), integrated scheduling of handling equipment (H. Y. K. Lau & Zhao, 2008), integrated scheduling of cranes, vehicles, and storage platforms at automated container terminals (Zhou et al., 2020; Homayouni et al., 2014) are some key areas that GA based algorithms have been applied in.

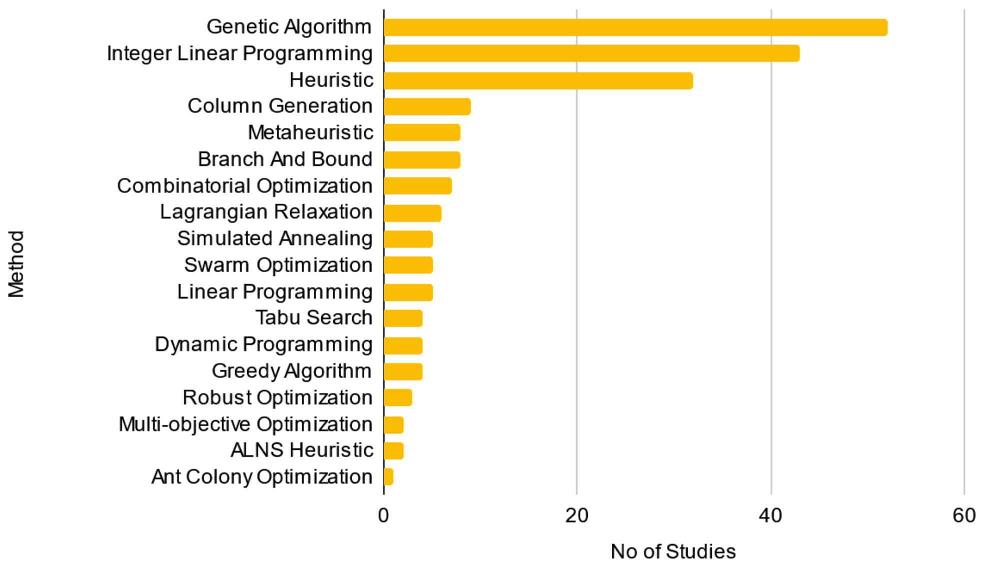


Figure 20: OR applications - Integrated operations in container terminals

Prominent applications of integer linear programming are integrated yard truck and yard crane scheduling (Cao et al., 2010; He et al., 2015) , and integrated BAP and QCA (Iris et al., 2015; Kenan et al., 2022; Diabat & Theodorou, 2014) are carried out using integer linear programming. Integrated remarshaling and berthing (Salido et al., 2011) and straddle carrier scheduling in maritime container terminal at import (Dkhil et al., 2018), integrated BAP and QCA (Shang et al., 2016), and integrated scheduling problem with dual-cycle operations (Zhang et al., 2014). In addition to that, heuristics, column generation, metaheuristics, branch and bound, combinatorial optimization, Lagrangian relaxation are the methods that have been applied frequently in the cluster.

One of the main barriers in integrated planning is identifying the exact workload limitations at each working station. A combination of heuristics and metaheuristics is proposed to mitigate the workload limitations by Hsu et al. (2021). The uncertainty that occurs through uncertain vessel arrival times at berths is a key variable to consider in integrated models. Rodrigues & Agra (2021) propose a robust approach for the integrated berth allocation and quay crane scheduling problem under uncertain arrival times. Developing scheduling problems through integrated approaches is a key limitation that is mentioned in the literature. However, Niu et al. (2021) propose a multi-objective bacterial colony optimization algorithm for an integrated container terminal scheduling problem.

Areas of numerical simulation, column generation, dynamic quay crane assignment, integrated yard template, dynamic container stacking, reducing internal congestion queuing theory, and planner role can be suggested as trending research directions under cluster 4: Integrated operations in container terminals. Weerasinghe et al. (2021) highlight the importance of integrated planning in container terminals. Three directions are suggested, uncertainty, planner role, and the integration between planning functions. According to Bai et al. (2021) social perspectives of maritime management can be investigated to enhance the sustainability aspect of container terminal operations. It can be suggested to link studies with cluster 1 to provide more compressive results through simulation under integrated studies according to the observations of the study.

3.3.2.5 Cluster 5 - Container transportation

3.3.2.5.1 Container transportation and its evolution

Containers are transported within the terminal and both into and out of the facility. Therefore, optimizing internal transport is critical for any container terminal. Hence, decision support systems that help to schedule container transportation including internal and external truck scheduling play a vital role within this cluster (Petering, 2011; Van Hee & Wijbrands, 1988). Abdelmagid et al. (2021) discuss the truck appointment scheduling models and directions for future research by conducting a review study. Abdelmagid et al. (2021) further highlight the vessel berthing time and the truck turnaround time as the two most critical factors to consider in scheduling trucks. In internal truck scheduling, yard trucks (terminal tractors) and Inter-terminal Transportation (ITT) are considered.

Chen, Govindan, & Golias (2013) propose a queueing-based bi-objective model for optimizing truck arrival patterns reducing truck emissions at container terminals in a low carbon economy. Zheng et al. (2016) propose to solve truck scheduling on a dedicated transportation route using integer linear programming. Yard truck scheduling (Homayouni et al., 2012; Cao et al., 2010), truck assignment problem (Vahdani et al., 2019), and ITT (Heilig et al., 2017c) are the areas that heuristics have been applied as a method to solve optimization problems. ITT (K Tierney et al., 2014), truck appointment systems (Torkjazi et al., 2018) and yard truck deployment (Chargui, Zouadi, El Fallahi, et al., 2021) are the key areas that integer linear programming has been applied. Tabu search algorithms and GA-based frameworks have been frequently used under this cluster to improve container terminal operations planning (Guo et al., 2021).

3.3.2.5.2 Trending methodologies: Container transportation

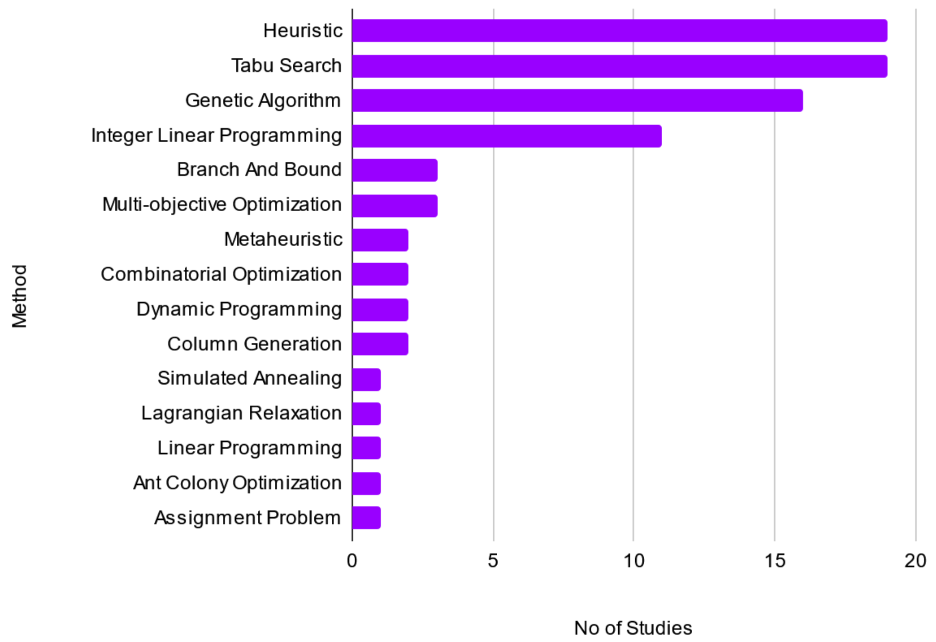


Figure 21: OR applications - Container transportation

Considering multi constraints in a system is one of the challenges that is faced in developing models. Xu et al. (2021) propose a hybrid genetic algorithm and simulated annealing model that eliminates the challenge of considering multi constraints within the system. Xu et al. (2021) further argue that mixed-integer nonlinear programming can contribute to developing truck appointment systems with multi constraints. It is critical to integrate different perspectives into one study. However, Fan et al. (2019) propose a combined approach that considers both the hybrid genetic algorithms and variable neighborhood search to introduce green practices into the terminal appointment systems.

Cluster 5: Container transportation, suggests truck appointment systems, discrete event simulation, and optimal vehicle routing as trending research directions. Caballini et al. (2020) find that combined data mining – optimization approach to manage truck operations using TAS, reduce empty truck trips by 34%. However, studies on ITT discuss a bird's eye view of integrating operations while terminals are demanding studies on implementing ITT operating systems. Since it is critical to implement operating systems by connecting different types of TOS, it will be an interesting area for future research. Perera & Perera (2022) explain pixel-oriented mobility modelling in container transport as a solution. Further, machine learning techniques can be suggested towards optimizing truck movements since it connects with various aspects that cannot be controlled by the terminal operator. ITT operations should be optimized while truck appointment systems are focused within external truck movements.

3.3.3 Evolution and future research directions

The areas of OR in maritime logistics industry, green port, robust optimization, energy consumption, mathematical modeling, truck appointment system, maritime transport, uncertainty, numerical simulation, particle swarm optimization appears as trending topics with a frequency of 8 times or more (Figure 22). From Gharehgozli et al. (2017), to Sun et al. (2021) have illustrated their problem within the area of OR in maritime industry. Shang et al. (2016) begin the discussion on robust optimization while Xiang & Liu (2021), Lujan et al. (2021) and Rodrigues & Agra (2021) introduce their studies following the same direction.

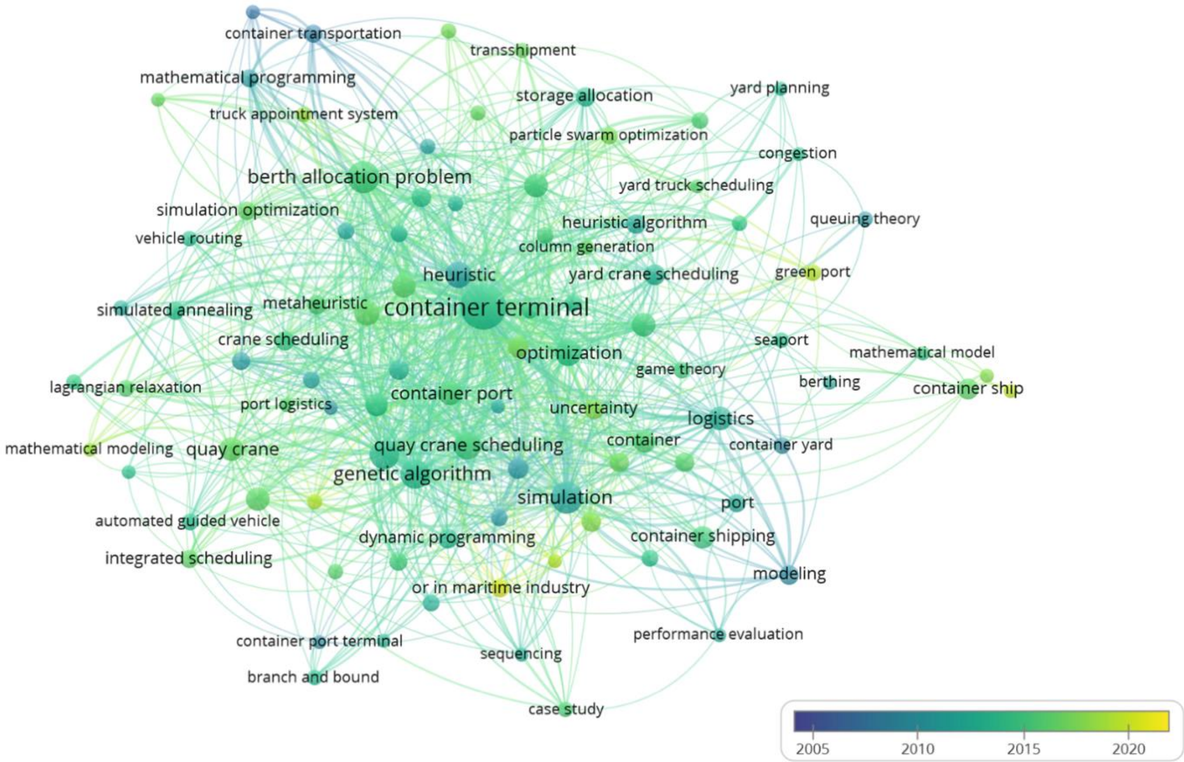


Figure 22 : Evolution – OR applications in container terminal operations planning

The discussion on green ports is one of the high demand research directions. Optimum terminal truck allocation (Esmer et al., 2010), CO_2 emission evaluation of yard tractors during loading (Yu et al., 2017), decision support systems for investigating green practices (Longo, 2019), low carbon berth allocation under uncertainty (Zhen et al., 2021), yard cranes transformation and deployment (Tan et al., 2022) are the main areas that green port concept has focused on. Bai & Lam (2014) suggest that environmental impact assessments are needed to enhance the green operations further. Xin et al. (2014) discuss energy-aware control for automated container terminals. One of the main observations was 4-5 studies have been published under these trending areas in 2021.

4 PHASE 2 - OPTIMIZING ITT TRUCK FLOWS USING FUZZY LOGIC

4.1 Introduction

4.1.1 ITT operations

Our extensive literature review discusses how the ITT function is operated (2.1). This section focus how ITT helps to improve the collaboration between container terminals as a separate planning function within the same port.

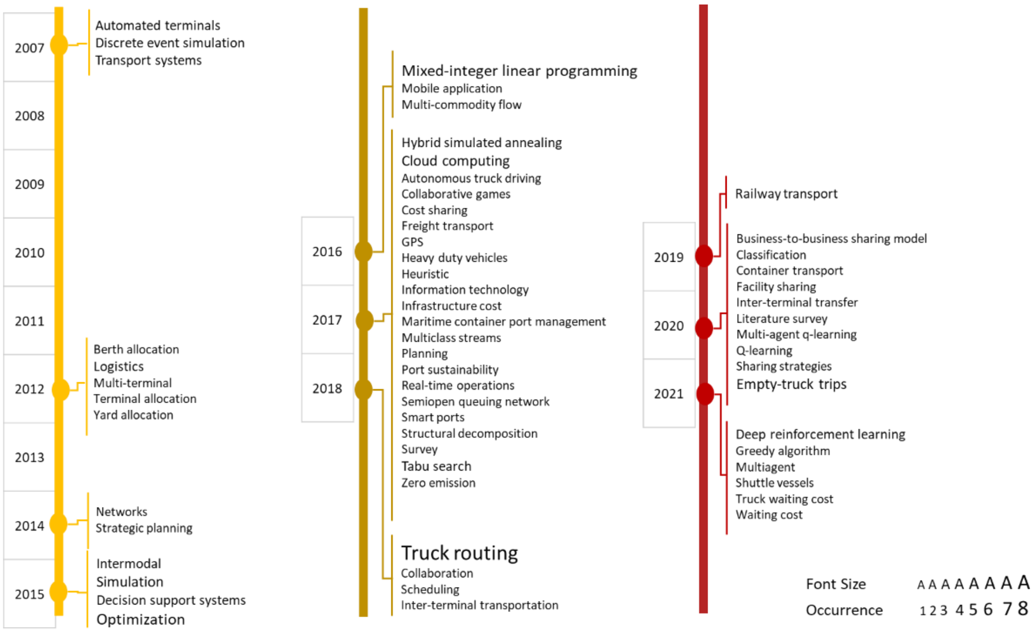


Figure 23: Areas covered under ITT operations- Average publications year and occurrences

Figure 23 explains how the studies on ITT operations have evolved with its focuses. Duinkerken et al., (2006) and Duinkerken et al., (2007) have conducted their studies on ITT operations while bringing automated container terminals, discrete event simulation and transport systems into the discussion. Reefke, (2010) develops a simulation of container traffic flows at a metropolitan seaport including ITT operations. Lack of integration, holism, and customizability are mentioned as key problems in ITT operations simulations by Reefke, (2010). A mathematical model has been developed for ITT by Tierney et al., (2014). Reducing the delays in transshipments can be reduced through optimizing ITT operations (Tierney et al., 2014).

Hendriks et al., (2012) have focused on the allocation of calling vessels cyclically for multi-terminal container operators highlighting ITT operations. Optimizing yard operations considering multi-terminal connectivity has also been investigated (Lee et al., 2012). Intramodality and hinterland transport affect ITT operations (Hu et al., 2019). Decision Support Systems (DSS) play a vital role in ITT operations. Improving DSS is the key to integrate ITT operations. Nieuwkoop et al., (2014) has built a deterministic minimum cost flow model for ITT operations. Nieuwkoop et al., (2014) propose strategies to mitigate internal port congestion by identifying internal and external truck flows. Hendriks et al., (2012), Nieuwkoop et al., (2014), Schepler et al., (2017) and Song et al., (2021) have used Mixed-Integer Linear Programming (MILP) to optimize ITT operations.

Cloud computing and mobile applications have been used to optimize truck routing in ITT avoiding empty trips and high costs, emissions, and additional traffic volume (Heilig et al., 2016). According to Spruijt et al., (2017) practical application of zero-emission Automatic Guided Trucks (AGTs) for the transport of containers is tested in port of Rotterdam. Gharehgozli et al., (2017) have proposed cost sharing as a collaborative approach in ITT.

Spruijt et al., (2017) proposed an autonomous system for handling ITT while focusing zero emission. Implementing autonomous operations in ITT is difficult due to gaps in integration between terminals. Schepler et al., (2017) introduce a heuristic approach to planning multi-terminal and multi-modal maritime container ports. Semi-open queuing network for ITT operations is introduced by Mishra et al., (2017). Tabu search has also been used in modeling ITT truck routing (Hu et al., 2018). Ma et al., (2020) conduct a real case study to evaluate a business-to-business sharing model in Hong Kong port to solve a real-world problem.

4.1.2 Research gaps and objectives – Phase 2

The research gaps (2.3.5) that are identified in the literature review (2) direct us to develop a systematic review of container terminal operations optimization. The systematic review (3) identifies 5 research clusters that elaborate evolution and trends in areas in container terminal operations optimization including simulation, scheduling and automation, quayside operations, integrated operations, and container transportation. After carefully evaluating the trends and publications in each cluster, we identify that the following percentages (Appendix A) of studies are covered under each cluster, simulation (28.14%), scheduling and automation (37.95%), quayside operations (28.08%), integrated operations (36.79%), and container transportation (12.39%).

The finding clearly shows the number of studies that are conducted under cluster 5, container transportation is limited. Discovering this fact motivates us to conduct our second phase under cluster 5, container transportation. As per the main research gap, *developing collaborative frameworks for ITT operations is needed more attention to improve the performance of container terminal operations* as per the research directions that are identified under the cluster, container transportation (Gharehgozli et al., 2017; Jin & Kim, 2018; Qu Hu et al., 2019a; Heilig et al., 2017a). Further, Weerasinghe et al., (2022) argue that the yard-to-gate interface can be optimized using integrated approaches further. Therefore, *improve the integration between yard-to-gate interface must be addressed* is defined as the second research gap for developing the phase 2 of the project. This gap is identified under the third cluster that discusses integration operations further.

Therefore, *optimizing ITT truck flows by integrating yard-to-gate interfaces in container terminals* is defined as the main objective of phase 2 of the project. Therefore, the title for phase 2 is defined as *Optimizing ITT truck flows using fuzzy logic* after introducing the methodology for the phase as fuzzy logic in 4.2.2.

4.2 Methodology – Phase 2

4.2.1 Feasible methodologies

Table 5: Methodologies in previous studies

	Authors & year	Methodology
1	Duinkerken et al., (2006)	Discrete event simulation
2	Lee et al., (2012)	Heuristics
3	Hendriks et al., (2012)	MILP
4	Tierney et al., (2014)	Integer programming
5	Nieuwkoop et al., (2014)	MILP
6	Schroer et al., (2015)	Discrete event simulation
7	Shijie Li et al., (2015)	MILP
8	Zheng et al., (2014)	Model Predictive Control
9	Heilig et al., (2016)	Simulated annealing
10	Hu et al., (2016)	Tabu search
11	Li et al., (2016)	Logic-based benders decomposition
12	Heilig & Voß, (2017)	Bibliometric Analysis
13	Heilig et al., (2017)	Simulated annealing
14	Gharehgozli et al., (2017)	Generic simulation model
15	Schepler et al., (2017)	MILP
16	Mishra et al., (2017)	Semi-open queuing Networks
17	Hu et al., (2018)	Tabu search
18	Hu et al., (2019)	Integer programming
19	Ma et al., (2020)	Business-to-business sharing model
20	Adi et al., (2020)	Deep reinforcement learning
21	Nellen et al., (2020)	Literature survey
22	Adi et al., (2020)	Q-learning-based techniques
23	Adi et al., (2020)	Multi-agent Q-learning
24	Song et al., (2021)	Greedy algorithm; MILP
25	Adi et al., (2021)	Deep reinforcement learning
26	Xiao et al., (2022)	MILP

Table 6 introduces 26 studies under ITT operations with the methodologies that studies employed. Nellen et al., (2020) and Heilig & Voß, (2017) conduct two recent review studies under the domain. The most frequent application can be identified as integer models. Hendriks et al., (2012), Nieuwkoop et al., (2014), Schepler et al., (2017), Xiao et al., (2022), Tierney et al., (2014), Hu et al., (2019) and Song et al., (2021) conduct their studies introducing integer models (integer programming & MILP) as per our extensive search on Scopus.

Table 6: Methodologies employed in ITT operations in previous studies

Methods applied in ITT studies	**Number of studies**
Mixed-integer linear programming	5
Tabu search	2
Simulated annealing	2
Integer programming	2
Discrete event simulation	2
Deep reinforcement learning	2
Semi open queuing Networks	1
Q-learning-based techniques	1
Multi-agent Q-learning	1
Model Predictive Control	1
Logic-based benders decomposition	1
Literature survey	1
Heuristics	1
Greedy algorithm	1
Generic simulation model	1
Business-to-business sharing model	1
Bibliometric Analysis	1

Deep reinforcement learning is considered by Adi et al., (2020) and (Adi et al., 2021). Duinkerken et al., (2006) and Schroer et al., (2015) build their models using discrete event simulation technique. A generic simulation model is proposed by Gharehgozli et al., (2017). A solution which is supported by greedy algorithm and mixed-integer linear programming is introduced by Song et al., (2021). Heuristics are also used to model ITT operations (D.-H. Lee et al., 2012). Adi et al., (2020) introduce Q-learning-based techniques to solve ITT operations problems. Semi-open queuing networks technique is proposed by Mishra et al., (2017). Heilig et al., (2016) and Heilig et al., (2017) conduct their studies to improve ITT operations using simulated annealing. Tabu search has also been proposed as a feasible technique to optimize ITT operations.

The most frequent method that is employed to optimize ITT operations can be identified as MILP. MILP models have been applied in areas; scheduling optimization (Xiao et al., 2022), strategic allocation of cyclically calling vessels (Hendriks et al., 2012), decision support for vehicle configuration determination in ITT system design (Nieuwkoop et al., 2014), global planning in a multi-terminal and multi-modal maritime container port (Schepler et al., 2017), planning shuttle vessel operations in large container terminals based on waterside congestion cases (Song et al., 2021). As Table 6 describes tabu search, simulated annealing, integer programming, discrete event simulation, and deep reinforcement learning are the techniques that have been employed by two studies for each. Other techniques that are mentioned in Table 6 are used once in previous studies under ITT operations.

However, all these proposed techniques such as integer programming and discrete event simulation end up with strict solutions. ITT operations need flexibility to be adjusted in uncertain conditions. It is critical to optimize ITT operations since the fundamentals of ITT operations are integration and collaboration. These fixed methods cannot support decision makers to adjust the solution according to the ongoing conditions. The decision-makers must use their experience in taking decisions in such uncertainties. We find that Fuzzy Inference Systems (FIS) facilitate flexibility in control systems (Phruksaphanrat & Tanthatemee, 2012).

4.2.2 Fuzzy logic

Lotfi A. Zadeh is the founder of many fuzzy-related concepts. Figure 24 explains how Zadeh, (1965) argues that precise statements lose meaning and meaningful statements lose precision as complexity rises (Svitek et al., 2021).

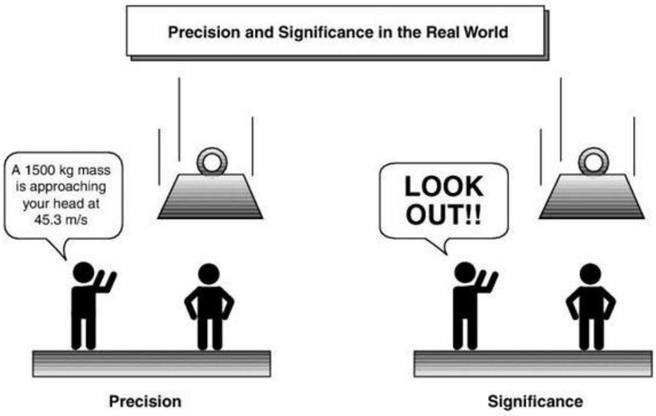
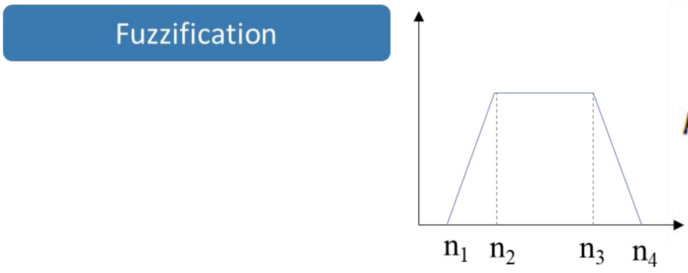


Figure 24: Precision and significance in the real world
Source: Madsen, (2015)

As Figure 24 explains systems need that significance through their' precision to take more relevant decisions. The naturalness of the approach which is taken by fuzzy logic makes the process simpler (Díaz-Curbelo et al., 2020). Five steps can be identified in developing fuzzy models; 1. fuzzification of inputs, 2. applying fuzzy operator, 3. implication method, 4. aggregate all outputs, 5. defuzzification.

4.2.2.1 Fuzzification

In the first step, it is needed to recognize inputs and outputs for fuzzification. Identifying the most relevant membership function is important to proceed with the process of fuzzy logic. The tool that is used to apply in the process should be identified at the beginning of the process. MATLAB has been employed as the tool to develop the fuzzy logic model. Figure 25 explains the first step of fuzzy logic, fuzzification. Explanations and algorithms have been introduced by Xiao et al., (2012) to explain the trapezoidal membership function that is used in this study to develop the mathematical concepts. Simply the inputs and outputs are categorized internally in this step.



$$\mu_{\tilde{n}}(x) = \begin{cases} 0, & x < n_1, \\ \frac{x-n_1}{n_2-n_1}, & n_1 \leqslant x \leqslant n_2, \\ 1, & n_2 \leqslant x \leqslant n_3, \\ \frac{x-n_4}{n_3-n_4}, & n_3 \leqslant x \leqslant n_4, \\ 0, & x > n_4. \end{cases}$$

Xiao et al., (2012)

Figure 25: Fuzzification

4.2.2.2 Applying fuzzy operator

Once the inputs are labeled internally, the rules can be generated. The rules connect inputs and outputs through logic gates of "AND" and "OR". An example of risk matrix can be explained to elaborate how the fuzzification and applying fuzzy operators are explained. There are two main inputs in a risk matrix; 1. Likelihood and 2. Consequence. The risk is calculated as the output. In fuzzification, likelihood and consequence are labeled based on their magnitude.

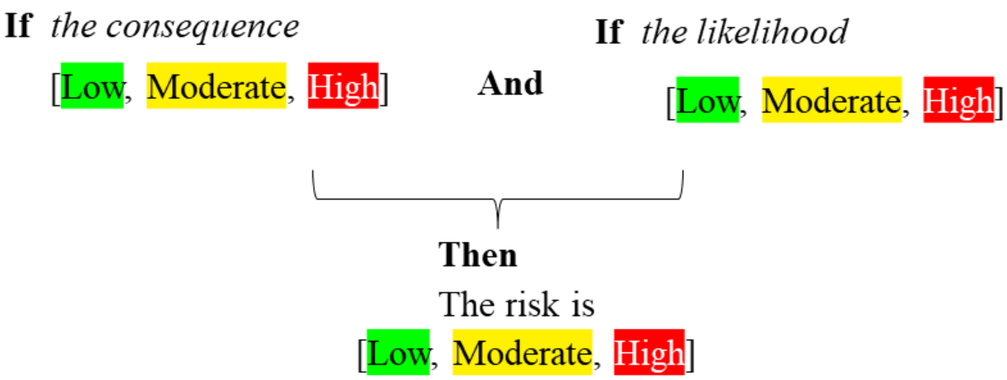


Figure 26: Applying fuzzy operator

Figure 26 explains how the inputs connect with outputs with its degree of membership; low, moderate, and high. This explains the basics of developing rules in fuzzy logic.

4.2.2.3 The implication method and aggregate all inputs

The output can be obtained once the rules are included in the fuzzy system. It is calculated for each rule which represents the step of applying the implication method. As the third step of the FIS, all the rules are calculated.

Figure 27: The implication method and aggregate all inputs

As Figure 27 explains the overall output is calculated as an aggregated answer of all the rules which are pre-defined. The same example that is introduced in Figure 26 is expanded in Figure 27 to explain the steps further in a risk model to calculate risks.

4.2.2.4 Defuzzification

Defuzzification is the last step of building a FIS. The centroid method is used as the defuzzification technique in this study. The centroid point of the aggregated inputs is calculated as the answer in this step. Simply, inputs are fuzzified in the first step of FIS. The fuzzified answer is defuzzified through the centroid method in this step. Finalized answer represents the overall output of given inputs by considering all the rules that are fixed.

4.3 Analysis

4.3.1 Identifying inputs and outputs in FIS

The major problem in ITT operations is the complexity of integration (4.1.2). The reason is that the different terminals maintain the standards of their operations. Therefore, proposing fixed plans for ITT is not going to succeed as it was planned. Schedules have two components; 1. Time and 2. Allocation. Time is the critical factor that the plan alters rapidly (Weerasinghe et al., 2021). The inputs and outputs are defined as the first sub-step of fuzzification. The main categories of the inputs are identified as; 1. Yard capacity for ITT deliveries and 2. ITT (delivery) truck arrival rates at gates. Yard capacity represents the terminal perspective while ITT truck arrivals indicates the dynamic of ITT truck allocations. Both the identified input variables highlight the integration of yard to gate interface. The proposed FIS can control the ITT allocation based on the given scenario that indicates current truck arrival rates and possible yard operations. The proposed structure for the FIS is introduced in Figure 28 with fuzzy reasoning.

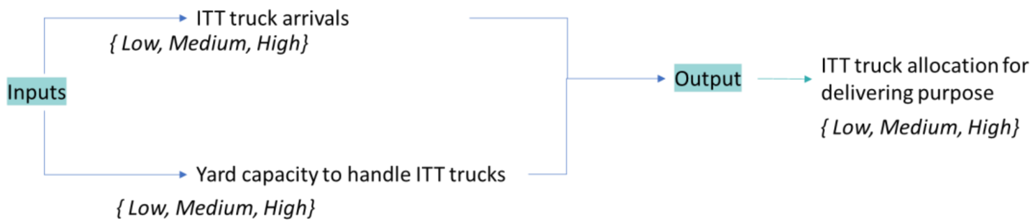


Figure 28: FIS system structure

The ranges of values are calculated based on the collected data. Variables are labeled internally as; *High - H, Medium - M, Low – L*, which are well known as defining linguistic values in fuzzy reasoning (Phruksaphanrat & Tanthatemee, 2012). In this case, ranges for yard capacity and truck allocation strategy (output) are defined with similar values to obtain most ideal strategy for yard flexibility.

4.3.2 Data collection

The data collection is conducted in a reputed container port in the Asian region. The container port is ranked within first 25 global container ports where the contribution of our study can be positioned. Three container terminals are operated in this container port. The following data points were collected in the data collection (week) within the three-container terminal system.

- C_A - Average hourly yard capacity at Terminal A (hour h+1)
- T_A - Average hourly ITT trucks arrival rate at Terminal A (hour h)
- C_B - Average hourly yard capacity at Terminal B (hour h)
- T_B - Average hourly ITT trucks arrival rate at Terminal B (hour h+1)
- C_C - Average hourly yard capacity at Terminal C (hour h)
- T_C - Average hourly ITT trucks arrival rate at Terminal C (hour h+1)

4.3.3 Building the FIS using MATLAB software

4.3.3.1 The structure of the model

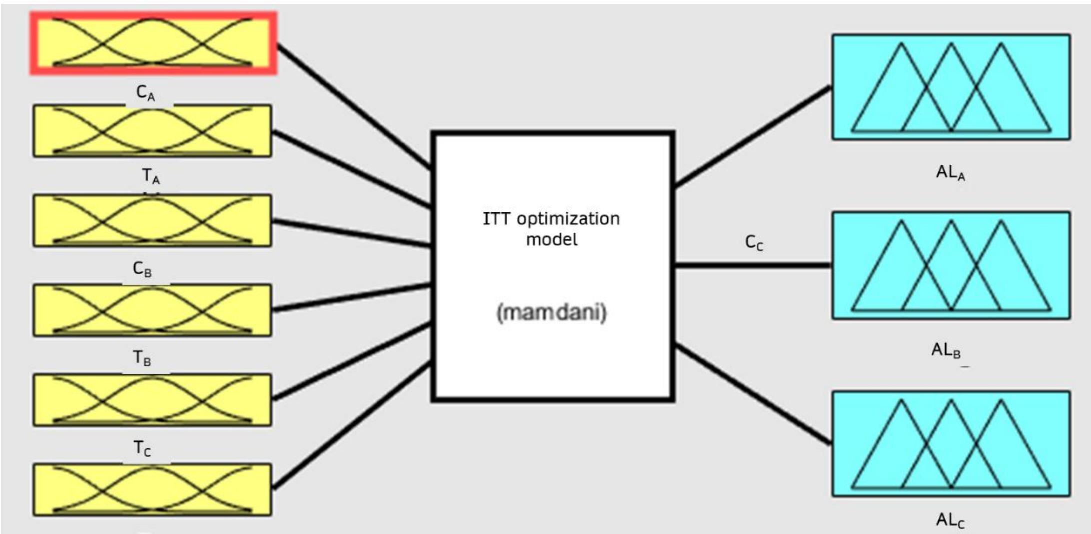


Figure 29: Model with inputs and outputs

The model is built using MATLAB software. Mamdani type fuzzy inference system is developed as in Figure 29. Three components; 1. fuzzy inputs, 2. fuzzy outputs and 3. fuzzy rules can be highlighted in a FIS.

The output represents the allocation strategy for each terminal. Once the six inputs are given, the output can be obtained. The outputs are defined as follows,

- AL_A - ITT delivery truck allocation for Terminal A
- AL_B - ITT delivery truck allocation for Terminal C
- AL_C - ITT delivery truck allocation for Terminal C

4.3.3.2 Fuzzification – Inputs and outputs

The ranges of values are calculated based on the collected data. Variables, *Yard Capacity (CiJ), Truck Arrivals (TiJ), and Allocation (ALiJ)* are labeled internally as; *J = High - H, Medium - M, Low - L* for each terminal *A, B, and C*. These ranges are defined based on the available information of container terminals. The trapezoidal membership function is explained in Figure 25.

Figure 30, Figure 31, Figure 32 explain how the linguistic values are defined for each container terminal. Table 7, Table 8 and Table 9 explain the numbers that define the linguistic values. Figure 25 explains how the points of trapezoidal membership function are defined as the numbers are introduced in Table 7, Table 8 and Table 9.

Terminal A has the highest ITT capacity (delivery) per hour which is 180 moves per hour. Terminal B and Terminal C can handle 150 and 120 moves per hour respectively. Total number of trucks has been identified as 200 for the scenario. Therefore, the maximum number of trucks that can reach per hour should be 200 with the assumption as well as the observation that a truck cannot return to a same terminal within an hour in the considered scenario. The truck allocation must follow the yard capacity as the key principle where it supports to maintain the flexibility of the yard operations.

Table 7: Membership function for Terminal A

Variable	*$V_I J$*		
i = A, B, C	V= C, T, AL, and J = High - H, Medium - M, Low - L		
	$C_A L$	$C_A M$	$C_A H$
Yard Capacity (CiJ)	[0 0 45 90]	[45 67.5 112.5 135]	[90 135.5 180 180]
	$T_A L$	$T_A M$	$T_A H$
Truck Arrivals (TiJ)	[0 0 45 90]	[45 67.5 112.5 135]	[90 135 200 200]
	$AL_A L$	$AL_A M$	$AL_A H$
Allocation (ALiJ)	[0 0 45 90]	[45 67.5 112.5 135]	[90 135.5 180 180]

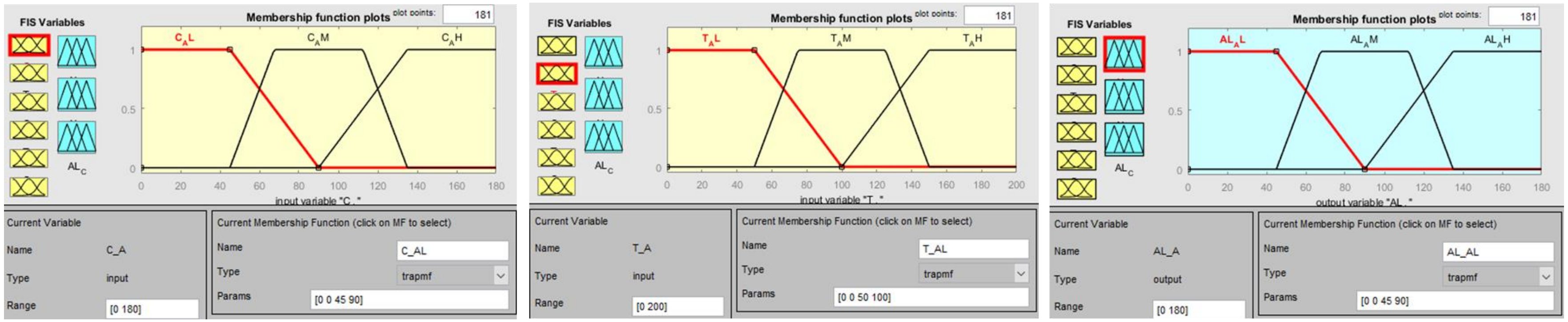


Figure 30: Labeling variables - Terminal A

Table 8: Membership function for Terminal B

Variable	$V_I\,J$		
i = A, B, C	V= C, T, AL, and J = High - H, Medium - M, Low - L		
	C_BL	C_BM	C_BH
Yard Capacity (CiJ)	[0 0 37.5 75]	[37.5 56.25 93.75 112.5]	[75 112.5 150 150]
	T_BL	T_BM	T_BH
Truck Arrivals (TiJ)	[0 0 37.5 75]	[37.5 56.25 93.75 112.5]	[75 112.5 200 200]
	AL_BL	AL_BM	AL_BH
Allocation (ALiJ)	[0 0 37.5 75]	[37.5 56.25 93.75 112.5]	[75 112.5 150 150]

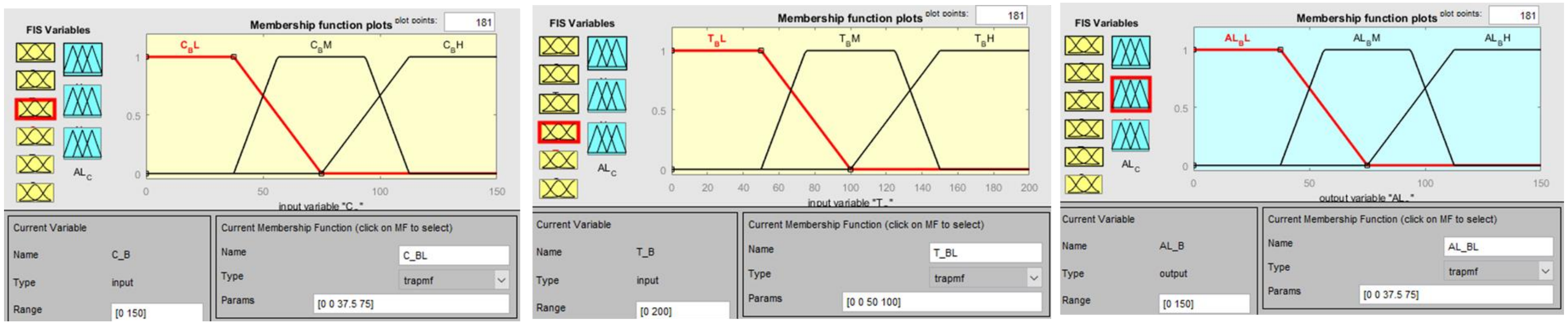


Figure 31: Labeling variables - Terminal B

Table 9: Membership function for Terminal C

Variable	*$V_I J$*		
i = A, B, C	V= C, T, AL, and J = High - H, Medium - M, Low - L		
	$C_C L$	$C_C M$	$C_C H$
Yard Capacity (CiJ)	[0 0 30 60]	[30 45 75 90]	[60 90 120 120]
	$T_C L$	$T_C M$	$T_C H$
Truck Arrivals (TiJ)	[0 0 30 60]	[30 45 75 90]	[60 90 200 200]
	$AL_C L$	$AL_C M$	$AL_C H$
Allocation (ALiJ)	[0 0 30 60]	[30 45 75 90]	[60 90 120 120]

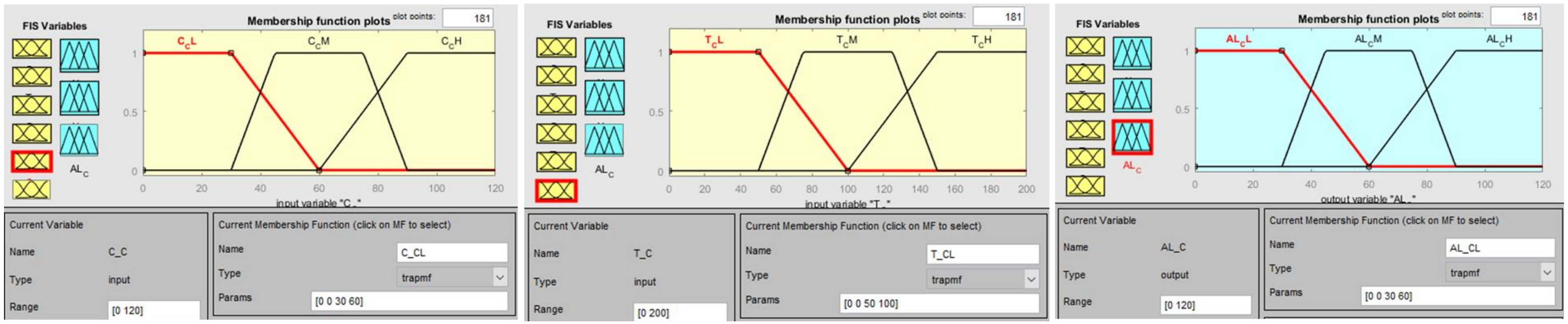


Figure 32: Labeling variables - Terminal C

4.3.3.3 Applying fuzzy operators

The rules should be defined in the second step of building FIS. First, the number of possibilities that can occur in the system is calculated. The possibilities are identified where the six inputs are divided into three categories as low, medium, and high for each input. Then the output is identified as a low, medium, and high for each output. 729 rules have been defined by following the procedure (Figure 33).

For considering a terminal

If the **yard capacity** is	**If** the ITT **truck arrivals rate** is	**Then** the ITT truck allocation is
Low	Low	Low
Low	Medium	Low
Low	High	Low
Medium	Low	Medium
Medium	Medium	Medium
Medium	High	Low
High	Low	High
High	Medium	High
High	High	High

Figure 33: Common practice in defining rules

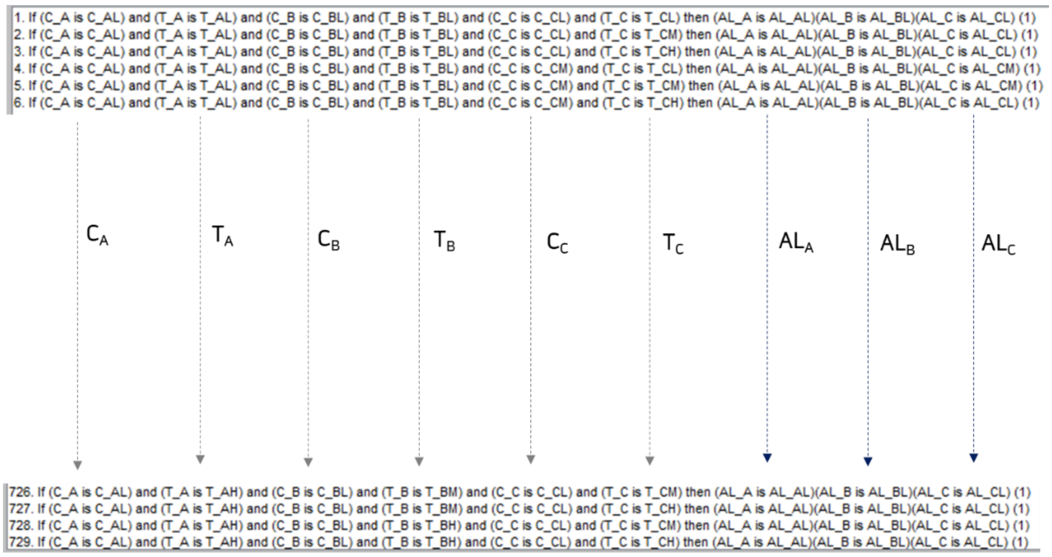


Figure 34: View of the “edit rules” - MATLAB

The “AND” function is applied as the fuzzy operator in each rule since the scenarios appear at the same time.

4.3.3.4 Implication method and aggregate all inputs

The output can be obtained once the model is run after defining rules. MATLAB rule viewer allows to calculate the output for each variable by altering the inputs. Simply the rule viewer can be used as the dashboard of allocations. The ITT operator can understand how many trucks should be needed for the operation by reading the rule viewer. The exact numbers which are identified as the inputs can be included in the FIS. Then the output can be obtained as it is displayed in Figure 35 and Table 10.

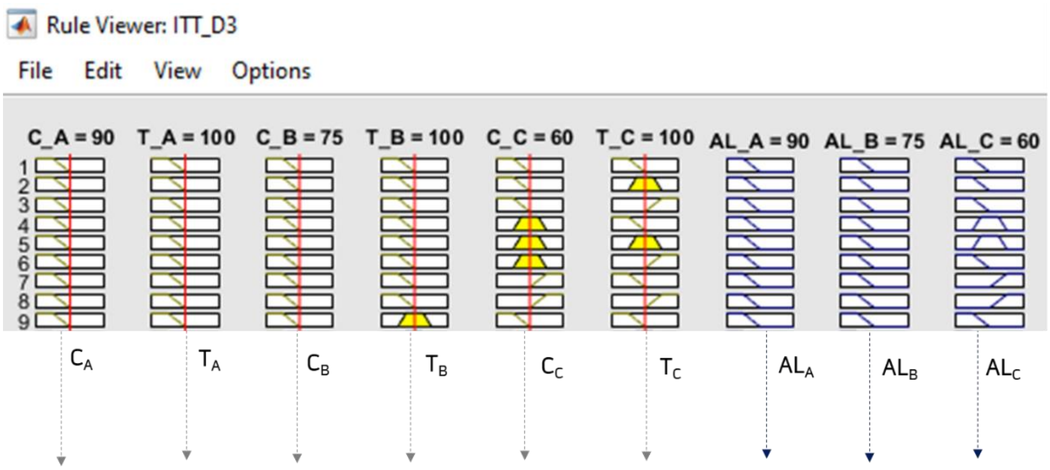


Figure 35: Rule viewer in MATLAB

Table 10: Entering inputs and obtaining outputs using rule viewer - MATLAB

Inputs						Outputs		
[C_A	T_A	C_B	T_B	C_C	T_C]	[AL_A	AL_B	AL_C]

4.3.3.5 Defuzzification

Defuzzification is the step where the final output is calculated as the aggregated answer by considering all the rules in FIS. The centroid mechanism is used in MATLAB to obtain the final output. Table 11 introduces a few examples of entering values for inputs and obtaining allocations for each terminal.

Table 11: Example calculations using the FIS

Inputs						Outputs		
[C_A	T_A	C_B	T_B	C_C	T_C]	[AL_A	AL_B	AL_C]
[90	100	75	100	60	100]	[90	75	60]
[70	90	90	20	60	90]	[74	88	56]
[20	70	50	120	60	10]	[38	53	60]
[70	20	50	120	10	70]	[70	53	25]
[150	30	100	100	50	60]	[142	97	42]

4.3.4 Collaborative truck sharing strategy

As Table 10 displays, the total of the allocated trucks exceeds the maximum number of allocations in some cases. We propose to release internal terminal trucks for ITT operations as a collaborative approach in such scenarios. Less complicated quay operations allow high capacities in the yard for ITT operations in each terminal. It reduces the internal terminal truck movements within the terminal within a period of time. As a result, internal terminal trucks are idling. Therefore, idling internal terminal trucks can be operated as ITT trucks when the terminal demands more ITT operations in yards. This directs towards a higher efficiency and a higher resource utilization.

4.3.5 ITT trucks allocation strategy for container terminals

4.3.5.1 Scenario 1 – Only a variable is available

The proposed FIS needs six inputs for running the model smoothly while the allocation for each terminal can be obtained when there is only one variable is available either the capacity or truck arrival rates. The Figure 36, Figure 37 and Figure 38 display the graphs with their related inputs.

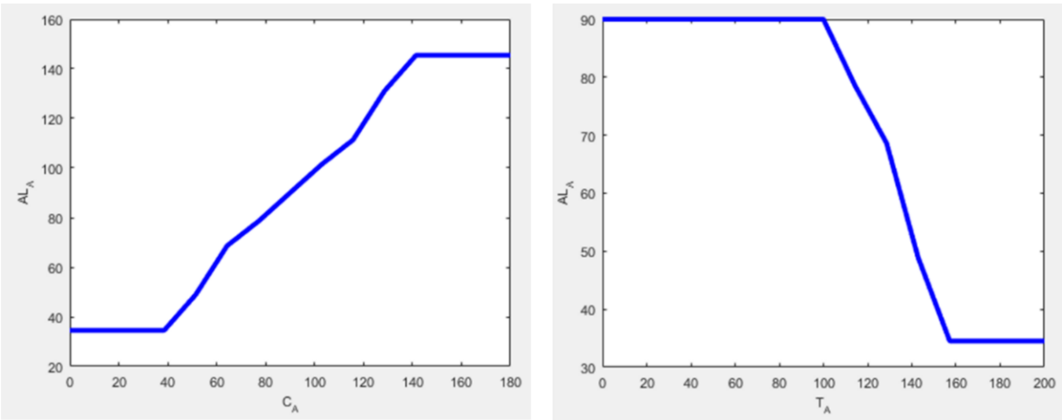


Figure 36: Allocation for Terminal A – When only Yard capacity or Truck arrivals rate is given

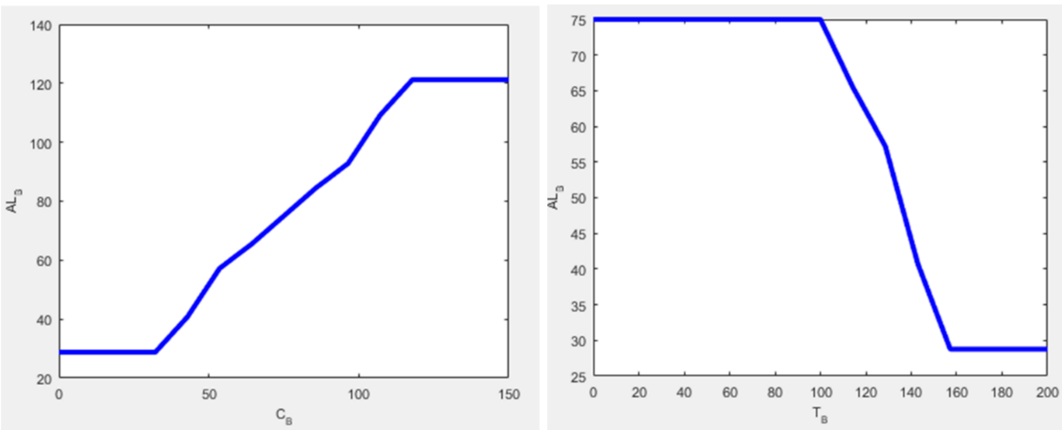


Figure 37: Allocation for Terminal B - When only Yard capacity or Truck arrivals rate is given

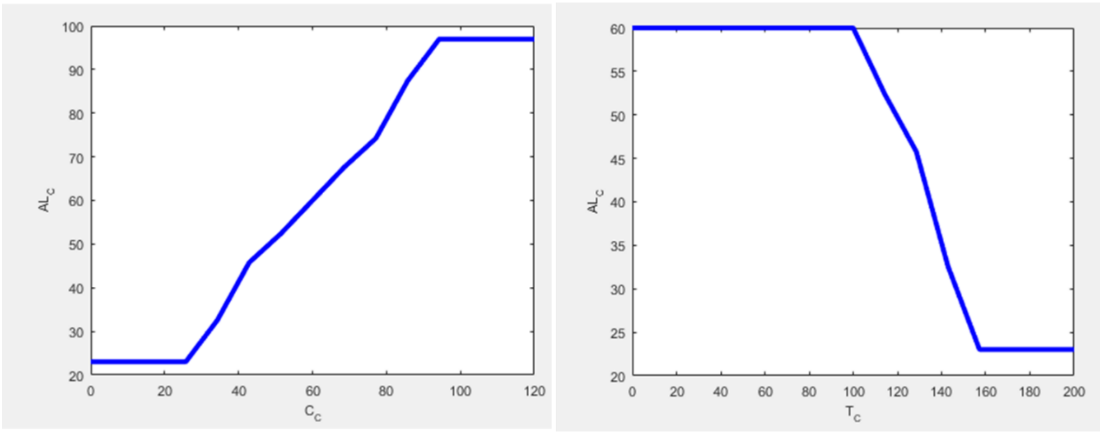


Figure 38: Allocation for Terminal C - When only Yard capacity or Truck arrivals rate is given

Identified truck allocation must be increased when the capacity of the yards is increased. Similarly, the truck allocation must be restricted when the truck arrival rates are increased. Allocation levels depend on the capacity of each terminal. Truck arrivals can vary with the same range for all the terminals.

4.3.5.2 Scenario 2 – Both the inputs are available for each terminal

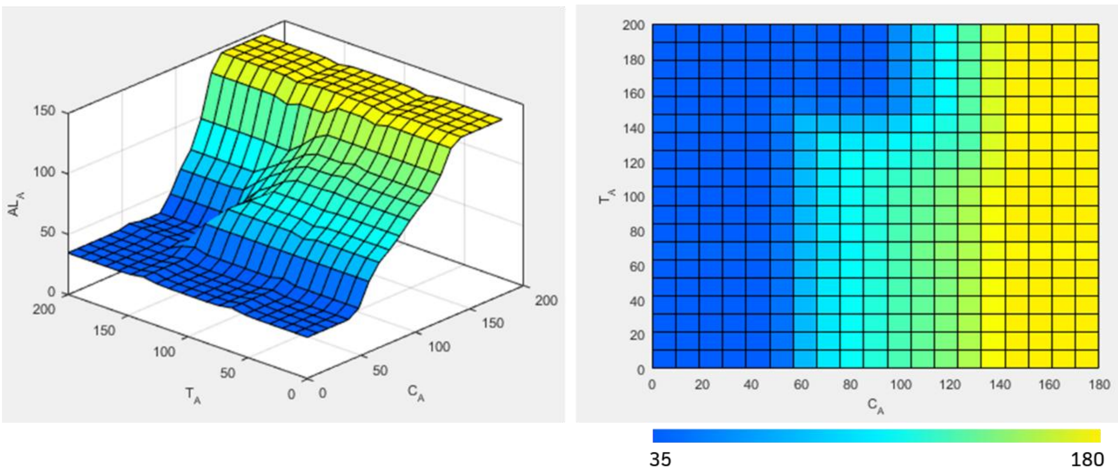


Figure 39: Truck allocation for Terminal A

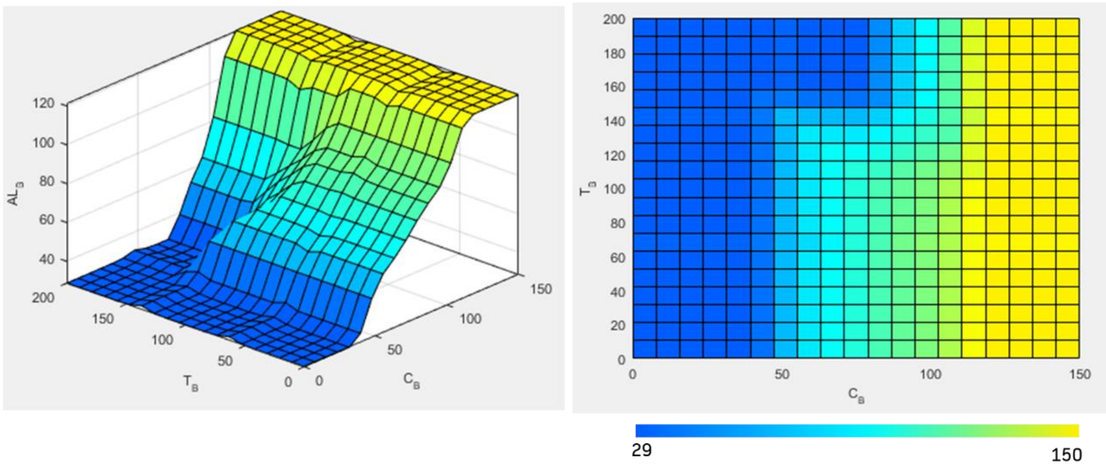


Figure 40: Truck allocation for Terminal B

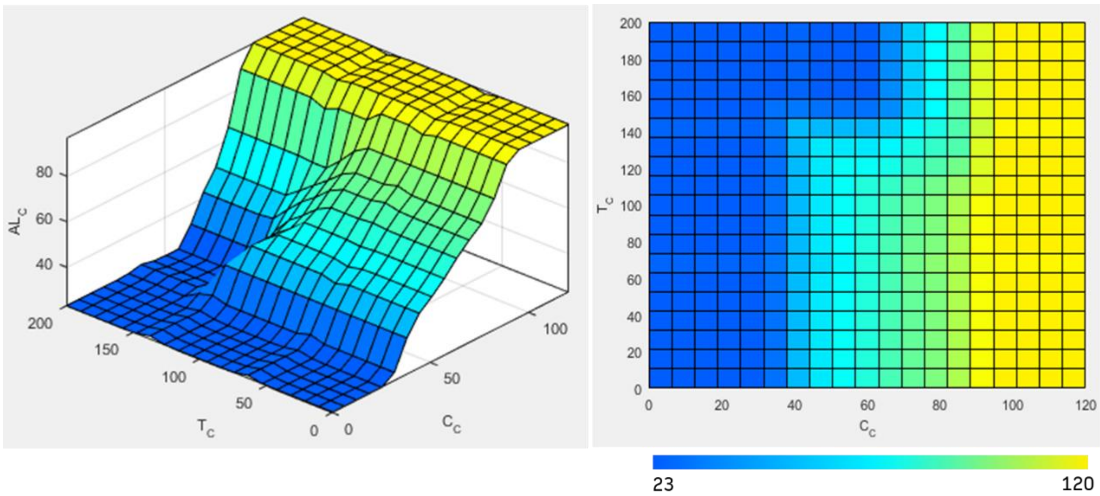


Figure 41: Truck allocation for Terminal C

The allocation for each terminal can be calculated with high accuracy when both inputs are available. Figure 39, Figure 40, Figure 41 display a three-dimensional (3D) view of capacity vs truck allocation and how the allocation can be displayed. Similarly, Figure 39, Figure 40, Figure 41 reveal the allocation in pseudo color matrix grids that have been created using MATLAB. Each graph has shown the range of truck allocations based on the obtained value.

5 DISCUSSION

5.1 Key findings

5.1.1 Phase 1 - Optimizing container terminal operations: A systematic review of operations research applications

As a novel contribution, we identify seven clusters within previously published 27 review studies within the scope: 1) Truck appointment systems, 2) Containerization and technology, 3) Computational modeling, 4) Container terminal automation, 5) Integrated operations, 6) Modeling and simulation and 7) Yard optimization. Consequently, we find that the area of OR under container terminal optimization was not covered as the pure focus of any of the review studies after 2007. Similarly, there are no systematic review study is conducted in previous studies according to the systematic search in Scopus.

Phase 1, *optimizing container terminal operations: a systematic review of operations research applications* is conducted following the research gaps and objectives derived in initial literate review (2.3.5). The systematic review is conducted after defining the exact paper pool which includes 1631 studies following the systematic process defined in 3.1. As a result, it is found that the growth rate as 45% per annum is surpassed within the scope by recording an 11.16% number of studies in 2021 out of 1631 identified studies. Moreover, *European Journal of Operational Research* is the journal that records the highest contribution to the scope while Transportation Research Part E: Logistics and Transportation Review is in second place with a margin of four articles.

Undoubtedly, China, United States, South Korea, Singapore, Germany, Hong Kong and Italy are the main contributors to research on container terminal operations optimization. In addition to that, K.H. Kim of Pusan National University, South Korea is the top author having contributed to 49 publications within the defined context. L. Zhen of Shanghai University, Shanghai takes second place on the list. With attention, Shanghai Maritime University, China is the leading institute in an operations research context in container terminals. The National University of Singapore is second on the list. The third place is taken by Dalian Maritime University, China.

Further, we find that 85.2% of studies have focused on exact planning function/ functions inside container terminal operations. 53.27% of the articles that focus on planning function/ functions have studied quayside planning while 46.73% of the studies focus on landside planning function. Moreover, five main research clusters are identified by analyzing the author keywords of the papers; 1. Simulating container terminal operations, 2. Scheduling operations and automating terminals, 3. Optimizing the quayside operations, 4. Integrated operations in container terminals and 5. Container transportation.

All things considered, future research directions are suggested under each cluster as follows; 1. robust optimization, impact on maritime transport, uncertainty, stowage planning, and liner shipping, 2. mathematical modeling, integrated scheduling, Lagrangian relaxation, combinatorial optimization, automated guided vehicles, 3.m particle swarm optimization, optimal fuel consumption, applications in meta-heuristic, dynamic berth, 4. numerical simulation, column generation, dynamic quay crane assignment, integrated yard template, dynamic container stacking, reducing internal congestion, and planner role, 5. truck appointment systems, discrete event simulation, and optimal vehicle routing. Importantly, our study helps future studies in container terminal optimization to identify research gaps that are needed to be filled.

Recent studies predominantly focus on OR in the maritime logistics industry, green ports, robust optimization, energy consumption, mathematical modeling, the truck appointment system, maritime transport, and uncertainty in container terminal operations. GA-based techniques, Integer linear programming, and heuristic algorithms appear as key OR tools to solve operational requirements in container terminal operations planning. Predominately, berth allocation is the most popular operations planning area within container terminal operations among authors.

5.1.2 Phase 2 - Optimizing ITT truck flows using fuzzy logic

The second phase of the project leads to optimize ITT truck flows using Fuzzy logic. Following Figure 42 explains how the study directs us to choose the topic.

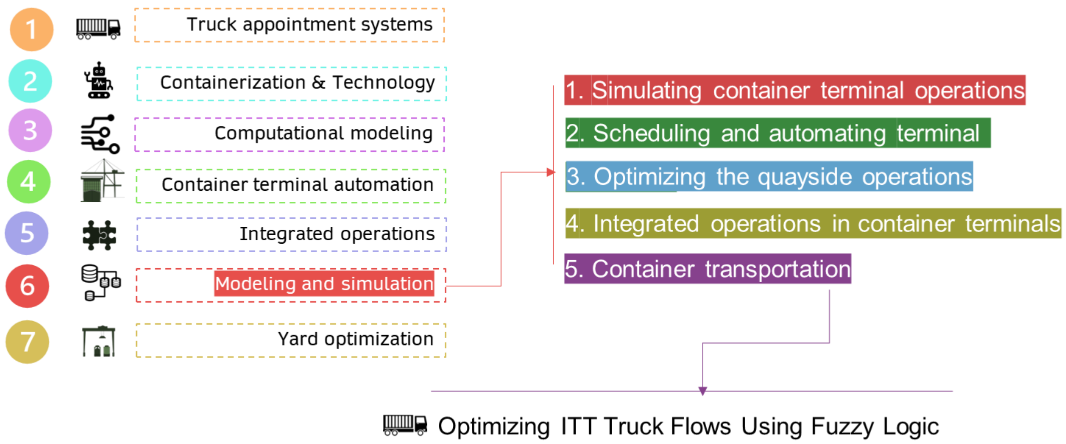


Figure 42: Path up to phase 2

FIS model is developed using two key inputs within a terminal; 1. Yard capacity for ITT operations, 2. ITT truck arrival rate. The model showcases how the ITT trucks should be allocated based on the yard capacity for next-hour operation and the current truck arrival rate. Subsequently, this strategy avoids unnecessary truck movements since the uncertainty in the system is reduced. The reason is the new allocation is always decided based on the current arrival rate. It should be noted that the model is developed up to three terminals system with two inputs for each terminal.

Altogether, the output showcases the allocation strategy for each terminal. How the ITT trucks can be allocated with each input is displayed (4.3.5). The allocation strategy cannot be decided only based on the yard requirement of the yard. The dashboard (MATLAB rule viewer) is operated to obtain exact numbers for allocation at each hour. The model enhances the collaborative framework through the dashboard by sharing the needed inputs from each terminal. Collaborative truck sharing initiatives can be proposed when terminal trucks are idling, and ITT trucks are over demanded.

6 CONCLUSION

The study focuses on applying optimization techniques in seaport container terminal operations contributes literature under two phases. First, the systematic review is conducted as the first review study after 2007 as well as the first systematic review of the scope. Operations research applications in container terminal operations are discussed by introducing five research clusters exploring future research directions. It immensely supports future studies to find research gaps more scientifically. Then the second phase is conducted by introducing a fuzzy logic model to optimize ITT truck flows in container terminal operations.

We find five main research clusters by analyzing the author keywords of the papers; 1. Simulating container terminal operations, 2. Scheduling operations and automating terminals, 3. Optimizing the quayside operations, 4. Integrated operations in container terminals and 5. Container transportation. Future research directions are identified for each research cluster with current trends. In a nutshell, green operations, and integrated and collaborative studies can be proposed for future research.

Phase 2 of the study is conducted to optimize ITT truck flows in container terminals. The proposed model can optimize ITT truck flows up to three terminals in one port. The model runs on the current ITT truck arrival rate and the yard demand for ITT operations. The model is built using MATLAB software. The features of the model can be enhanced in future studies within the aspects of collaborations and integrations. Moreover, the focus on industry-academia collaboration has been quite low within the identified scope despite the growth of publications in recent years. In the same fashion, more industry collaborative work is salient for the growth of this field. Along with that, future studies are encouraged to be of a more integrated nature that contributes to solving the uncertainty problem in container terminal operations. Importantly, emerging methods such as neural network models and rule-based models that use machine learning and artificial intelligence must be explored extensively to achieve expansive efficiencies.

7 REFERENCES

Abdel-Fattah, A., El-Tawil, A., & Harraz, N. (2013). An Integrated Operational Research and System Dynamics Approach for Planning Decisions in Container Terminals. *Engineering and Technology International Journal of Industrial Science and Engineering*, *7*. http://www.waset.org/publications/17095

Abdelmagid, A. M., Gheith, M. S., & Eltawil, A. B. (2021). A comprehensive review of the truck appointment scheduling models and directions for future research. *Transport Reviews*. https://doi.org/10.1080/01441647.2021.1955034

Abdelshafie, A., Salah, M., Kramberger, T., & Dragan, D. (2022). Repositioning and Optimal Re-Allocation of Empty Containers: A Review of Methods, Models, and Applications. *Sustainability (Switzerland)*, *14*(11). https://doi.org/10.3390/su14116655

Abeysooriya, H., Weerasinghe, B. A., & Perera, H. N. (2021). Optimizing Gate Queueing at Container Terminals to Facilitate Green Operations. *The Australian Maritime Logistics Research Network (AMLRN) 2021 Symposium*.

Adi, T N, Iskandar, Y. A., & Bae, H. (2020). Q-learning-based technique for reduction of number of empty-truck trips in inter-terminal transportation. *ICIC Express Letters, Part B: Applications*, *11*(10), 987–994. https://doi.org/10.24507/icicelb.11.10.987

Adi, T N, Iskandar, Y. A., Bae, H., & Choi, Y. (2020). *Reduction of number of empty-truck trips in inter-terminal transportation using multi-agent Q-learning*. 167–172. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85085955113&partnerID=40&md5=43780d4026e03b85c067cbcac2fb81ad

Adi, Taufik Nur, Bae, H., & Iskandar, Y. A. (2021). Interterminal truck routing optimization using cooperative multiagent deep reinforcement learning. *Processes*, *9*(10). https://doi.org/10.3390/pr9101728

Adi, Taufik Nur, Iskandar, Y. A., & Bae, H. (2020). Interterminal truck routing optimization using deep reinforcement learning. *Sensors (Switzerland)*, *20*(20), 1–20. https://doi.org/10.3390/s20205794

Agra, A., & Oliveira, M. (2018). MIP approaches for the integrated berth allocation and quay crane assignment and scheduling problem. *European Journal of Operational Research*, *264*(1), 138–148. https://doi.org/10.1016/j.ejor.2017.05.040

Al-Dhaheri, N., Jebali, A., & Diabat, A. (2016). The quay crane scheduling problem with nonzero crane repositioning time and vessel stability constraints. *Computers and Industrial Engineering*, *94*, 230–244. https://doi.org/10.1016/j.cie.2016.01.011

Alvarez, J. F., Longva, T., & Engebrethsen, E. S. (2010). A methodology to assess vessel berthing and speed optimization policies. *Maritime Economics and Logistics*, *12*(4), 327–346. https://doi.org/10.1057/mel.2010.11

Ambrosino, D., Sciomachen, A., & Tanfani, E. (2004). Stowing a containership: The master bay plan problem. *Transportation Research Part A: Policy and Practice*, *38*(2), 81–99. https://doi.org/10.1016/j.tra.2003.09.002

Angeloudis, P., & Bell, M. G. H. (2011). A review of container terminal simulation models. *Maritime Policy and Management*, *38*(5), 523–540. https://doi.org/10.1080/03088839.2011.597448

Azevedo, A. T., de Salles Neto, L. L., Chaves, A. A., & Moretti, A. C. (2018). Solving the 3D stowage planning problem integrated with the quay crane scheduling problem by representation by rules and genetic algorithm. *Applied Soft Computing Journal*, *65*, 495–516. https://doi.org/10.1016/j.asoc.2018.01.006

Bahadir, M. C., & Akdag, H. C. (2019). The System Dynamics Modelling for Container Capacity & Transportation Planning Policies. *Asian Journal of*

Shipping and Logistics, *35*(4), 200–212. https://doi.org/10.1016/j.ajsl.2019.12.007

Bai, X., & Lam, J. S. L. (2014). Dynamic regional port cluster development: case of the ports across Taiwan Strait. *GeoJournal*, *80*(5), 619–636. https://doi.org/10.1007/s10708-014-9567-5

Bai, X., Zhang, X., Li, K. X., Zhou, Y., & Yuen, K. F. (2021). Research topics and trends in the maritime transport: A structural topic model. *Transport Policy*, *102*(November 2020), 11–24. https://doi.org/10.1016/j.tranpol.2020.12.013

Bartošek, A., & Marek, O. (2013). Quay Cranes in Container Terminals. *Transactions on Transport Sciences*, *6*(1), 9–18. https://doi.org/10.2478/v10158-012-0027-y

Beens, M.-A., & Ursavas, E. (2016). Scheduling cranes at an indented berth. *European Journal of Operational Research*, *253*(2), 298–313. https://doi.org/10.1016/j.ejor.2016.02.038

Behera, J., Bhuta, C., & Thorpe, G. (2000). Management information systems: An overview of practices at marine container terminals in Australia and Asia. *Transportation Quarterly*, *54*(4), 59–73. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0034264968&partnerID=40&md5=798b6ce3a52c6e0c409b8cb7f82ba561

Beškovnik, B. (2008). Measuring and increasing the productivity model on maritime container terminals. *Pomorstvo*, *22*(2), 171–183. https://www.scopus.com/inward/record.uri?eid=2-s2.0-60649084632&partnerID=40&md5=ebcc4659ecea4f0f2bee06550641bea5

Bierwirth, C., & Meisel, F. (2010). A survey of berth allocation and quay crane scheduling problems in container terminals. *European Journal of Operational Research*, *202*(3), 615–627. https://doi.org/10.1016/j.ejor.2009.05.031

Blankmann, H., & Klimbie, B. (1985). Container terminal along the Rhine. An overview of existing and planned transhipment facilities. *ROTTERDAM EUROPOORT DELTA*, *4*, *1985*, 19–23. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0013763157&partnerID=40&md5=49079a6a4b2cf5c1e05391574d10daa6

Böse, J. W. (2020). Handbook of terminal planning. In *Operations Research/ Computer Science Interfaces Series* (Vol. 49, Issue 1). https://doi.org/10.1007/978-1-4419-8408-1

Buhrkal, K., Zuglian, S., Ropke, S., Larsen, J., & Lusby, R. (2011). Models for the discrete berth allocation problem: A computational comparison. *Transportation Research Part E: Logistics and Transportation Review*, *47*(4), 461–473. https://doi.org/10.1016/j.tre.2010.11.016

Caballini, C., Gracia, M. D., Mar-Ortiz, J., & Sacone, S. (2020). A combined data mining – optimization approach to manage trucks operations in container terminals with the use of a TAS: Application to an Italian and a Mexican port. *Transportation Research Part E: Logistics and Transportation Review*, *142*. https://doi.org/10.1016/j.tre.2020.102054

Cai, B, Huang, S., Liu, D., & Dissanayake, G. (2014). Rescheduling policies for large-scale task allocation of autonomous straddle carriers under uncertainty at automated container terminals. *Robotics and Autonomous Systems*, *62*(4), 506–514. https://doi.org/10.1016/j.robot.2013.12.007

Cai, Binghuang, Huang, S., Liu, D., & Dissanayake, G. (2014). Rescheduling policies for large-scale task allocation of autonomous straddle carriers under uncertainty at automated container terminals. *Robotics and Autonomous Systems*, *62*(4), 506–514. https://doi.org/10.1016/j.robot.2013.12.007

Cao, J., Shi, Q., & Lee, D.-H. (2010). Integrated quay crane and yard truck schedule problem in container terminals. *Tsinghua Science and Technology*, *15*(4), 467–

474. https://doi.org/10.1016/S1007-0214(10)70089-4

Cao, J. X., Lee, D.-H., Chen, J. H., & Shi, Q. (2010). The integrated yard truck and yard crane scheduling problem: Benders' decomposition-based methods. *Transportation Research Part E: Logistics and Transportation Review*, *46*(3), 344–353. https://doi.org/10.1016/j.tre.2009.08.012

Carlo, H J, Vis, I. F. A., & Roodbergen, K. J. (2014). Storage yard operations in container terminals: Literature overview, trends, and research directions. *European Journal of Operational Research*, *235*(2), 412–430. https://doi.org/10.1016/j.ejor.2013.10.054

Carlo, H J, Vis, I. F. A., & Roodbergen, K. J. (2015). Seaside operations in container terminals: literature overview, trends, and research directions. *Flexible Services and Manufacturing Journal*, *27*(2–3), 224–262. https://doi.org/10.1007/s10696-013-9178-3

Carlo, Héctor J., Vis, I. F. A., & Roodbergen, K. J. (2015). Seaside operations in container terminals: literature overview, trends, and research directions. *Flexible Services and Manufacturing Journal*, *27*(2–3), 224–262. https://doi.org/10.1007/s10696-013-9178-3

Caserta, M., Schwarze, S., & Voß, S. (2012). A mathematical formulation and complexity considerations for the blocks relocation problem. *European Journal of Operational Research*, *219*(1), 96–104. https://doi.org/10.1016/j.ejor.2011.12.039

Castilla-Rodríguez, I., Expósito-Izquierdo, C., Melián-Batista, B., Aguilar, R. M., & Moreno-Vega, J. M. (2020). Simulation-optimization for the management of the transshipment operations at maritime container terminals. *Expert Systems with Applications*, *139*. https://doi.org/10.1016/j.eswa.2019.112852

Chamchang, P., & Niyomdecha, H. (2021). Impact of service policies on terminal gate efficiency: a simulation approach. *Cogent Business and Management*, *8*(1). https://doi.org/10.1080/23311975.2021.1975955

Chang, D., Jiang, Z., Yan, W., & He, J. (2010). Integrating berth allocation and quay crane assignments. *Transportation Research Part E: Logistics and Transportation Review*, *46*(6), 975–990. https://doi.org/10.1016/j.tre.2010.05.008

Chao, S.-L., & Lin, P.-H. (2021). Minimizing overstowage in master bay plans of large container ships. *Maritime Economics and Logistics*, *23*(1), 71–93. https://doi.org/10.1057/s41278-019-00126-6

Chargui, K., Zouadi, T., El Fallahi, A., Reghioui, M., & Aouam, T. (2021). Berth and quay crane allocation and scheduling with worker performance variability and yard truck deployment in container terminals. *Transportation Research Part E: Logistics and Transportation Review*, *154*. https://doi.org/10.1016/j.tre.2021.102449

Chargui, K., Zouadi, T., Fallahi, A. E., Reghioui, M., & Aouam, T. (2021). Coupling the ILS optimisation algorithm and a simulation process to solve the travelling quay-crane worker assignment and balancing problem. *Journal of the Operational Research Society*. https://doi.org/10.1080/01605682.2021.1907241

Chen, G., Govindan, K., & Golias, M. M. (2013). Reducing truck emissions at container terminals in a low carbon economy: Proposal of a queueing-based bi-objective model for optimizing truck arrival pattern. *Transportation Research Part E: Logistics and Transportation Review*, *55*, 3–22. https://doi.org/10.1016/j.tre.2013.03.008

Chen, G., Govindan, K., & Yang, Z. (2013). Managing truck arrivals with time windows to alleviate gate congestion at container terminals. *International Journal of Production Economics*, *141*(1), 179–188. https://doi.org/10.1016/j.ijpe.2012.03.033

Chen, J. H., & Bierlaire, M. (2017). The study of the unidirectional quay crane scheduling problem: complexity and risk-aversion. *European Journal of Operational Research*, *260*(2), 613–624. https://doi.org/10.1016/j.ejor.2017.01.007

Chen, J. H., Lee, D. H., & Cao, J. X. (2012). A combinatorial benders' cuts algorithm for the quayside operation problem at container terminals. *Transportation Research Part E: Logistics and Transportation Review*, *48*(1), 266–275. https://doi.org/10.1016/j.tre.2011.06.004

Chen, P., Fu, Z., Lim, A., & Rodrigues, B. (2004). Port yard storage optimization. *IEEE Transactions on Automation Science and Engineering*, *1*(1), 26–37. https://doi.org/10.1109/TASE.2004.829412

Chen, S., & Zeng, Q. (2021). Carbon-efficient scheduling problem of electric rubber-tyred gantry cranes in a container terminal. *Engineering Optimization*. https://doi.org/10.1080/0305215X.2021.1972293

Chou, C.-C., & Fang, P.-Y. (2021). Applying expert knowledge to containership stowage planning: an empirical study. *Maritime Economics and Logistics*, *23*(1), 4–27. https://doi.org/10.1057/s41278-018-0113-0

Chu, F, He, J., Zheng, F., & Liu, M. (2019). Scheduling multiple yard cranes in two adjacent container blocks with position-dependent processing times. *Computers and Industrial Engineering*, *136*, 355–365. https://doi.org/10.1016/j.cie.2019.07.013

Chu, Feng, He, J., Zheng, F., & Liu, M. (2019). Scheduling multiple yard cranes in two adjacent container blocks with position-dependent processing times. *Computers and Industrial Engineering*, *136*, 355–365. https://doi.org/10.1016/j.cie.2019.07.013

Chung, Y.-G., Randhawa, S. U., & McDowell, E. D. (1988). A simulation analysis for a transtainer-based container handling facility. *Computers and Industrial Engineering*, *14*(2), 113–125. https://doi.org/10.1016/0360-8352(88)90020-4

Cordeau, J.-F., Laporte, G., Legato, P., & Moccia, L. (2005). Models and tabu search heuristics for the berth-allocation problem. *Transportation Science*, *39*(4), 526–538. https://doi.org/10.1287/trsc.1050.0120

Dadashi, A., Dulebenets, M. A., Golias, M. M., & Sheikholeslami, A. (2017). A novel continuous berth scheduling model at multiple marine container terminals with tidal considerations. *Maritime Business Review*, *2*(2), 142–157. https://doi.org/10.1108/mabr-02-2017-0010

Davarzani, H., Fahimnia, B., Bell, M., & Sarkis, J. (2016). Greening ports and maritime logistics: A review. *Transportation Research Part D: Transport and Environment*, *48*, 473–487. https://doi.org/10.1016/j.trd.2015.07.007

Delgado, A., Jensen, R. M., Janstrup, K., Rose, T. H., & Andersen, K. H. (2012). A Constraint Programming model for fast optimal stowage of container vessel bays. *European Journal of Operational Research*, *220*(1), 251–261. https://doi.org/10.1016/j.ejor.2012.01.028

Dell, R. F., Royset, J. O., & Zyngiridis, I. (2009). Optimizing container movements using one and two automated stacking cranes. *Journal of Industrial and Management Optimization*, *5*(2), 285–302. https://doi.org/10.3934/jimo.2009.5.285

Diabat, A., & Theodorou, E. (2014). An Integrated Quay Crane Assignment and Scheduling Problem. *Computers and Industrial Engineering*, *73*(1), 115–123. https://doi.org/10.1016/j.cie.2013.12.012

Díaz-Curbelo, A., Espin Andrade, R. A., & Gento Municio, Á. M. (2020). The Role of Fuzzy Logic to Dealing with Epistemic Uncertainty in Supply Chain Risk Assessment: Review Standpoints. *International Journal of Fuzzy Systems*, *22*(8), 2769–2791. https://doi.org/10.1007/s40815-020-00846-5

Ding, D., & Chou, M. C. (2015). Stowage planning for container ships: A heuristic algorithm to reduce the number of shifts. *European Journal of Operational Research*, *246*(1), 242–249. https://doi.org/10.1016/j.ejor.2015.03.044

Ding, Y., Yang, Y., Heilig, L., Lalla-Ruiz, E., & Voss, S. (2021). Deployment and retrofit strategy for rubber-tyred gantry cranes considering carbon emissions. *Computers and Industrial Engineering*, *161*. https://doi.org/10.1016/j.cie.2021.107645

Dkhil, H., Yassine, A., & Chabchoub, H. (2018). Multi-objective optimization of the integrated problem of location assignment and straddle carrier scheduling in maritime container terminal at import. *Journal of the Operational Research Society*, *69*(2), 247–269. https://doi.org/10.1057/s41274-017-0184-9

Dragović, B, Park, N. K., Radmilović, Z., & Maraš, V. (2005). Simulation modelling of ship-berth link with priority service. *Maritime Economics and Logistics*, *7*(4), 316–335. https://doi.org/10.1057/palgrave.mel.9100141

Dragović, Branislav, Tzannatos, E., & Park, N. K. (2017). Simulation modelling in ports and container terminals: literature overview and analysis by research field, application area and tool. *Flexible Services and Manufacturing Journal*, *29*(1), 4–34. https://doi.org/10.1007/s10696-016-9239-5

Dubrovsky, O., Levitin, G., & Penn, M. (2002). A genetic algorithm with a compact solution encoding for the container ship stowage problem. *Journal of Heuristics*, *8*(6), 585–599. https://doi.org/10.1023/A:1020373709350

Duinkerken, M B, Dekker, R., Kurstjens, S. T. G. L., Ottjes, J. A., & Dellaert, N. P. (2007). Comparing transportation systems for inter-terminal transport at the Maasvlakte container terminals. In *Container Terminals and Cargo Systems: Design, Operations Management, and Logistics Control Issues* (pp. 37–61).

Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-49550-5_3

Duinkerken, Mark B., Dekker, R., Kurstjens, S. T. G. L., Ottjes, J. A., & Dellaert, N. P. (2006). Comparing transportation systems for inter-terminal transport at the Maasvlakte container terminals. *OR Spectrum*, *28*(4), 469–493. https://doi.org/10.1007/s00291-006-0056-1

Esmer, S., Cetin, I. B., & Tuna, O. (2010). A simulation for optimum terminal truck number in a turkish port based on lean and green concept. *Asian Journal of Shipping and Logistics*, *26*(2), 277–296. https://doi.org/10.1016/S2092-5212(10)80006-9

Fan, H., Ren, X., Guo, Z., & Li, Y. (2019). Truck scheduling problem considering carbon emissions under truck appointment system. *Sustainability (Switzerland)*, *11*(22). https://doi.org/10.3390/su11226256

Fazi, S. (2019). A decision-support framework for the stowage of maritime containers in inland shipping. *Transportation Research Part E: Logistics and Transportation Review*, *131*, 1–23. https://doi.org/10.1016/j.tre.2019.09.008

Fazlollahtabar, H., & Saidi-Mehrabad, M. (2015). Methodologies to Optimize Automated Guided Vehicle Scheduling and Routing Problems: A Review Study. *Journal of Intelligent and Robotic Systems: Theory and Applications*, *77*(3–4), 525–545. https://doi.org/10.1007/s10846-013-0003-8

Fernández, E., & Munoz-Marquez, M. (2022). New formulations and solutions for the strategic berth template problem. *European Journal of Operational Research*, *298*(1), 99–117. https://doi.org/10.1016/j.ejor.2021.06.062

Fibrianto, H. Y., Kang, B., Kim, B., Marbach, A., Buer, T., Haasis, H.-D., Hong, S., & Kim, K. H. (2020). A Simulation Study of a Storage Policy for a Container Terminal. *LDIC*, *1*, 62–69. https://doi.org/10.1007/978-3-030-44783-0_6

Filom, S., Amiri, A. M., & Razavi, S. (2022). Applications of machine learning methods in port operations – A systematic literature review. *Transportation Research Part E: Logistics and Transportation Review*, *161*. https://doi.org/10.1016/j.tre.2022.102722

Gerken, P., Kotzab, H., & Unseld, H. G. (2020). Resource Sharing as a Management Concept for Digital Logistics Terminals. *LDIC*, *1*, 79–88. https://doi.org/10.1007/978-3-030-44783-0_8

Gharehgozli, A., Gharehgozli, O., & Li, K. (2021). Mixed integer programming models on scheduling automated stacking cranes. *International Journal of Business Analytics*, *8*(4), 11–33. https://doi.org/10.4018/IJBAN.2021100102

Gharehgozli, A H, de Koster, R., & Jansen, R. (2017). Collaborative solutions for inter terminal transport. *International Journal of Production Research*, *55*(21), 6527–6546. https://doi.org/10.1080/00207543.2016.1262564

Gharehgozli, A H, Vernooij, F. G., & Zaerpour, N. (2017). A simulation study of the performance of twin automated stacking cranes at a seaport container terminal. *European Journal of Operational Research*, *261*(1), 108–128. https://doi.org/10.1016/j.ejor.2017.01.037

Gharehgozli, Amir Hossein, de Koster, R., & Jansen, R. (2017). Collaborative solutions for inter terminal transport. *International Journal of Production Research*, *55*(21), 6527–6546. https://doi.org/10.1080/00207543.2016.1262564

Gharehgozli, Amir Hossein, Roy, D., & De Koster, R. (2016). Sea container terminals: New technologies and or models. *Maritime Economics and Logistics*, *18*(2), 103–140. https://doi.org/10.1057/mel.2015.3

Golias, M M, Boile, M., & Theofanis, S. (2009). Berth scheduling by customer service differentiation: A multi-objective approach. *Transportation Research Part E: Logistics and Transportation Review*, *45*(6), 878–892.

https://doi.org/10.1016/j.tre.2009.05.006

Golias, M M, Saharidis, G. K., Boile, M., Theofanis, S., & Ierapetritou, M. G. (2009). The berth allocation problem: Optimizing vessel arrival time. *Maritime Economics and Logistics*, *11*(4), 358–377. https://doi.org/10.1057/mel.2009.12

Golias, Mihalis M. (2011). A bi-objective berth allocation formulation to account for vessel handling time uncertainty. *Maritime Economics and Logistics*, *13*(4), 419–441. https://doi.org/10.1057/mel.2011.21

Görges, M., & Freitag, M. (2020). On the Influence of Structural Complexity on Autonomously Controlled Automobile Terminal Processes. *LDIC*, *2*, 42–51. https://doi.org/10.1007/978-3-030-44783-0_4

Grant, M. J., & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Information and Libraries Journal*, *26*(2), 91–108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Gunawardhana, J. A., Perera, H. N., & Thibbotuwawa, A. (2021). Rule-based dynamic container stacking to optimize yard operations at port terminals. *Maritime Transport Research*, *2*(March), 100034. https://doi.org/10.1016/j.martra.2021.100034

Guo, W., Ji, M., & Zhu, H. (2021). Multi-Period Coordinated Optimization on Berth Allocation and Yard Assignment in Container Terminals Based on Truck Route. *IEEE Access*, *9*, 83124–83136. https://doi.org/10.1109/ACCESS.2021.3086185

Guo, X., & Huang, S. Y. (2012). Dynamic space and time partitioning for yard crane workload management in container terminals. *Transportation Science*, *46*(1), 134–148. https://doi.org/10.1287/trsc.1110.0383

Güven, C., & Eliiyi, D. T. (2014). Trip allocation and stacking policies at a container terminal. *Transportation Research Procedia*, *3*(July), 565–573.

https://doi.org/10.1016/j.trpro.2014.10.035

Güven, C., & Eliiyi, D. T. (2018). Modelling and optimisation of online container stacking with operational constraints. *Maritime Policy and Management*, *46*(2), 201–216. https://doi.org/10.1080/03088839.2018.1450529

Hansen, P., Oğuz, C., & Mladenović, N. (2008). Variable neighborhood search for minimum cost berth allocation. *European Journal of Operational Research*, *191*(3), 636–649. https://doi.org/10.1016/j.ejor.2006.12.057

He, J, Chang, D., Mi, W., & Yan, W. (2010). A hybrid parallel genetic algorithm for yard crane scheduling. *Transportation Research Part E: Logistics and Transportation Review*, *46*(1), 136–155. https://doi.org/10.1016/j.tre.2009.07.002

He, J, Huang, Y., Yan, W., & Wang, S. (2015). Integrated internal truck, yard crane and quay crane scheduling in a container terminal considering energy consumption. *Expert Systems with Applications*, *42*(5), 2464–2487. https://doi.org/10.1016/j.eswa.2014.11.016

He, Junliang, Tan, C., & Zhang, Y. (2019). Yard crane scheduling problem in a container terminal considering risk caused by uncertainty. *Advanced Engineering Informatics*, *39*(November 2018), 14–24. https://doi.org/10.1016/j.aei.2018.11.004

Heilig, L., Lalla-Ruiz, E., & Voß, S. (2016). *Port-IO: A mobile cloud platform supporting context-aware inter-terminal truck routing*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84995814982&partnerID=40&md5=f3c05d79f74cf3b9e4c5524bfe4792f6

Heilig, L., Lalla-Ruiz, E., & Voß, S. (2017a). Multi-objective inter-terminal truck routing. *Transportation Research Part E: Logistics and Transportation Review*, *106*, 178–202. https://doi.org/10.1016/j.tre.2017.07.008

Heilig, L., Lalla-Ruiz, E., & Voß, S. (2017b). Multi-objective inter-terminal truck routing. *Transportation Research Part E: Logistics and Transportation Review*, *106*, 178–202. https://doi.org/10.1016/j.tre.2017.07.008

Heilig, L., Lalla-Ruiz, E., & Voß, S. (2017c). port-IO: an integrative mobile cloud platform for real-time inter-terminal truck routing optimization. *Flexible Services and Manufacturing Journal*, *29*(3–4), 504–534. https://doi.org/10.1007/s10696-017-9280-z

Heilig, L., & Voß, S. (2017). Inter-terminal transportation: an annotated bibliography and research agenda. *Flexible Services and Manufacturing Journal*, *29*(1), 35–63. https://doi.org/10.1007/s10696-016-9237-7

Hendriks, M. P. M., Armbruster, D., Laumanns, M., Lefeber, E., & Udding, J. T. (2012). Strategic allocation of cyclically calling vessels for multi-terminal container operators. *Flexible Services and Manufacturing Journal*, *24*(3), 248–273. https://doi.org/10.1007/s10696-011-9120-5

Homayouni, S. M., & Tang, S. H. (2013). Multi objective optimization of coordinated scheduling of cranes and vehicles at container terminals. *Mathematical Problems in Engineering*, *2013*. https://doi.org/10.1155/2013/746781

Homayouni, S. M., Tang, S. H., & Motlagh, O. (2014). A genetic algorithm for optimization of integrated scheduling of cranes, vehicles, and storage platforms at automated container terminals. *Journal of Computational and Applied Mathematics*, *270*, 545–556. https://doi.org/10.1016/j.cam.2013.11.021

Homayouni, S. M., Vasili, M. R., Kazemi, S. M., & Tang, S. H. (2012). Integrated scheduling of SP-AS/RS and handling equipment in automated container terminals. *42nd International Conference on Computers and Industrial Engineering 2012, CIE 2012*, *2*, 781–792. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84892996615&partnerID=40&md5=7828794f3b701692f5dc31ce69e9f78b

Hsu, H.-P., Tai, H.-H., Wang, C.-N., & Chou, C.-C. (2021). Scheduling of collaborative operations of yard cranes and yard trucks for export containers using hybrid approaches. *Advanced Engineering Informatics*, *48*. https://doi.org/10.1016/j.aei.2021.101292

Hsu, H.-P., Wang, C.-N., Fu, H.-P., & Dang, T.-T. (2021). Joint scheduling of yard crane, yard truck, and quay crane for container terminal considering vessel stowage plan: An integrated simulation-based optimization approach. *Mathematics*, *9*(18). https://doi.org/10.3390/math9182236

Hu, Q, Corman, F., Wiegmans, B., & Lodewijks, G. (2018). A tabu search algorithm to solve the integrated planning of container on an inter-terminal network connected with a hinterland rail network. *Transportation Research Part C: Emerging Technologies*, *91*, 15–36. https://doi.org/10.1016/j.trc.2018.03.019

Hu, Q, Wiegmans, B., Corman, F., & Lodewijks, G. (2019). Critical literature review into planning of inter-terminal transport: In port areas and the hinterland. *Journal of Advanced Transportation*, *2019*. https://doi.org/10.1155/2019/9893615

Hu, Qu, Luan, X., Corman, F., & Lodewijks, G. (2016). A Tabu Search Algorithm for Inter-terminal Container Transport. *IFAC-PapersOnLine*, *49*(3), 413–418. https://doi.org/10.1016/j.ifacol.2016.07.069

Hu, Qu, Wiegmans, B., Corman, F., & Lodewijks, G. (2019a). Critical literature review into planning of inter-terminal transport: In port areas and the hinterland. *Journal of Advanced Transportation*, *2019*. https://doi.org/10.1155/2019/9893615

Hu, Qu, Wiegmans, B., Corman, F., & Lodewijks, G. (2019b). Integration of inter-terminal transport and hinterland rail transport. *Flexible Services and Manufacturing Journal*, *31*(3), 807–831. https://doi.org/10.1007/s10696-019-09345-8

Hwan Kim, K., & Bae Kim, H. (1999). *Segregating space allocation models for container inventories in port container terminals*. *59*(1), 415–423. https://doi.org/10.1016/S0925-5273(98)00028-0

Imai, A., Nishimura, E., & Papadimitriou, S. (2008). Berthing ships at a multi-user container terminal with a limited quay capacity. *Transportation Research Part E: Logistics and Transportation Review*, *44*(1), 136–151. https://doi.org/10.1016/j.tre.2006.05.002

Imran, M. M. H., Ayob, A. F., & Jamaludin, S. (2021). Applications of artificial intelligence in ship berthing: A review. *Indian Journal of Geo-Marine Sciences*, *50*(11), 855–863. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85127586449&partnerID=40&md5=0e57ecfe987cfc0d7bbe0639914faaed

Iris, Ç., Pacino, D., Ropke, S., & Larsen, A. (2015). Integrated Berth Allocation and Quay Crane Assignment Problem: Set partitioning models and computational results. *Transportation Research Part E: Logistics and Transportation Review*, *81*, 75–97. https://doi.org/10.1016/j.tre.2015.06.008

Islam, S. (2017). Empty truck trips problem at container terminals: A review of causes, benefits, constraints and solution approaches. *Business Process Management Journal*, *23*(2), 248–274. https://doi.org/10.1108/BPMJ-06-2015-0086

Jacomino, L. A., Pérez, C. M., & Pérez, R. B. (2017). Literature review on objective functions for stacking of containers . *Inteligencia Artificial*, *20*(60), 28–50. https://doi.org/10.4114/intartif.vol20iss60pp28-50

Ji, M., Guo, W., Zhu, H., & Yang, Y. (2015). Optimization of loading sequence and rehandling strategy for multi-quay crane operations in container terminals. *Transportation Research Part E: Logistics and Transportation Review*, *80*, 1–19. https://doi.org/10.1016/j.tre.2015.05.004

Jin, B., Zhu, W., & Lim, A. (2014). Solving the container relocation problem by an improved greedy look-ahead heuristic. *European Journal of Operational Research*, *240*(3), 837–847. https://doi.org/10.1016/j.ejor.2014.07.038

Jin, X., & Kim, K. H. (2018). Collaborative inter-terminal transportation of containers. *Industrial Engineering and Management Systems*, *17*(3), 407–416. https://doi.org/10.7232/iems.2018.17.3.407

Kalmar. (2013). *Boosting efficiency*.

Karakas, S., Kirmizi, M., & Kocaoglu, B. (2021). Yard block assignment, internal truck operations, and berth allocation in container terminals: introducing carbon-footprint minimisation objectives. *Maritime Economics and Logistics*, *23*(4), 750–771. https://doi.org/10.1057/s41278-021-00186-7

Kastner, M, Nellen, N., Schwientek, A., & Jahn, C. (2021). Integrated simulation-based optimization of operational decisions at container terminals. *Algorithms*, *14*(2). https://doi.org/10.3390/a14020042

Kastner, Marvin, Lange, A.-K., & Jahn, C. (2020). Expansion Planning at Container Terminals. *LDIC*, *4*(D), 114–123. https://doi.org/10.1007/978-3-030-44783-0_11

Kaveshgar, N., & Huynh, N. (2015a). A genetic algorithm heuristic for solving the quay crane scheduling problem with time windows. *Maritime Economics and Logistics*, *17*(4), 515–537. https://doi.org/10.1057/mel.2014.31

Kaveshgar, N., & Huynh, N. (2015b). Integrated quay crane and yard truck scheduling for unloading inbound containers. *International Journal of Production Economics*, *159*, 168–177. https://doi.org/10.1016/j.ijpe.2014.09.028

Kenan, N., Jebali, A., & Diabat, A. (2022). The integrated quay crane assignment and scheduling problems with carbon emissions considerations. *Computers and Industrial Engineering*, *165*. https://doi.org/10.1016/j.cie.2021.107734

Kim, A., Park, H.-J., Park, J.-H., & Cho, S.-W. (2021). Rescheduling strategy for berth planning in container terminals: An empirical study from Korea. *Journal of Marine Science and Engineering*, *9*(5). https://doi.org/10.3390/jmse9050527

Kizilay, D, & Eliiyi, D. T. (2021). A comprehensive review of quay crane scheduling, yard operations and integrations thereof in container terminals. *Flexible Services and Manufacturing Journal*, *33*(1). https://doi.org/10.1007/s10696-020-09385-5

Kizilay, Damla, & Eliiyi, D. T. (2020). A comprehensive review of quay crane scheduling, yard operations and integrations thereof in container terminals. In *Flexible Services and Manufacturing Journal* (Issue 0123456789). Springer US. https://doi.org/10.1007/s10696-020-09385-5

Kon, W. K., Abdul Rahman, N. S. F., Md Hanafiah, R., & Abdul Hamid, S. (2020). The global trends of automated container terminal: a systematic literature review. *Maritime Business Review*, *6*(3), 206–233. https://doi.org/10.1108/MABR-03-2020-0016

Kong, L., Ji, M., & Gao, Z. (2021). Joint optimization of container slot planning and truck scheduling for tandem quay cranes. *European Journal of Operational Research*, *293*(1), 149–166. https://doi.org/10.1016/j.ejor.2020.12.005

Kurniawan, F., Musa, S. N., Moin, N. H., & Sahroni, T. R. (2022). A Systematic Review on Factors Influencing Container Terminal's Performance. *Operations and Supply Chain Management*, *15*(2), 174–192. https://doi.org/10.31387/oscm0490339

Laik, N., & Hadjiconstantnou, E. (2008). Container assignment and yard crane deployment in a container terminal: A case study. *Maritime Economics and Logistics*, *10*(1–2), 90–107. https://doi.org/10.1057/palgrave.mel.9100193

Larsen, R., & Pacino, D. (2021). A heuristic and a benchmark for the stowage planning problem. *Maritime Economics and Logistics*, *23*(1), 94–122.

https://doi.org/10.1057/s41278-020-00172-5

Lau, H. Y. K., & Zhao, Y. (2008). Integrated scheduling of handling equipment at automated container terminals. *Annals of Operations Research*, *159*(1), 373–394. https://doi.org/10.1007/s10479-007-0262-5

Lau, Y., Ducruet, C., Ng, A. K. Y., & Fu, X. (2017). Across the waves: a bibliometric analysis of container shipping research since the 1960s. *Maritime Policy and Management*, *44*(6), 667–684. https://doi.org/10.1080/03088839.2017.1311425

Lee, C.-Y., & Song, D.-P. (2017). Ocean container transport in global supply chains: Overview and research opportunities. *Transportation Research Part B: Methodological*, *95*, 442–474. https://doi.org/10.1016/j.trb.2016.05.001

Lee, D.-H., Jin, J. G., & Chen, J. H. (2012). Terminal and yard allocation problem for a container transshipment hub with multiple terminals. *Transportation Research Part E: Logistics and Transportation Review*, *48*(2), 516–528. https://doi.org/10.1016/j.tre.2011.09.004

Lee, D.-H., Wang, H. Q., & Miao, L. (2008). Quay crane scheduling with non-interference constraints in port container terminals. *Transportation Research Part E: Logistics and Transportation Review*, *44*(1), 124–135. https://doi.org/10.1016/j.tre.2006.08.001

Legato, P., Canonaco, P., & Mazza, R. M. (2009). Yard crane management by simulation and optimisation. *Maritime Economics and Logistics*, *11*(1), 36–57. https://doi.org/10.1057/mel.2008.23

Li, C.-L., & Vairaktarakis, G. L. (2004). Loading and unloading operations in container terminals. *IIE Transactions (Institute of Industrial Engineers)*, *36*(4), 287–297. https://doi.org/10.1080/07408170490247340

Li, C., Lu, Z., Han, X., Zhang, Y., & Wang, L. (2015). Integrated scheduling of a container handling system with simultaneous loading and discharging operations. *Engineering Optimization*, *48*(3), 397–414. https://doi.org/10.1080/0305215X.2015.1012077

Li, H., Peng, J., Wang, X., & Wan, J. (2021). Integrated Resource Assignment and Scheduling Optimization with Limited Critical Equipment Constraints at an Automated Container Terminal. *IEEE Transactions on Intelligent Transportation Systems*, *22*(12), 7607–7618. https://doi.org/10.1109/TITS.2020.3005854

Li, J., Zhang, Y., Ma, J., & Ji, S. (2018). Multi-Port Stowage Planning for Inland Container Liner Shipping Considering Weight Uncertainties. *IEEE Access*, *6*(c), 66468–66480. https://doi.org/10.1109/ACCESS.2018.2878308

Li, N., Haralambides, H., Sheng, H., & Jin, Z. (2022). A new vocation queuing model to optimize truck appointments and yard handling-equipment use in dual transactions systems of container terminals. *Computers and Industrial Engineering*, *169*. https://doi.org/10.1016/j.cie.2022.108216

Li, S, Negenborn, R. R., & Lodewijks, G. (2016). *A logic-based benders decomposition approach to improve coordination of inland vessels for inter-terminal transport: Vol. 9855 LNCS* (V. S., P. A., & R. M. (eds.); pp. 96–115). Springer Verlag. https://doi.org/10.1007/978-3-319-44896-1_7

Li, Shijie, Negenborn, R. R., & Lodewijks, G. (2015). A two phase approach for inter-terminal transport of inland vessels using preference-based and utility-based coordination rules. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *9335*, 281–297. https://doi.org/10.1007/978-3-319-24264-4_20

Li, X., Peng, Y., Huang, J., Wang, W., & Song, X. (2021). Simulation study on terminal layout in automated container terminals from efficiency, economic and environment perspectives. *Ocean and Coastal Management*, *213*. https://doi.org/10.1016/j.ocecoaman.2021.105882

Li, Y., Chang, D., Gao, Y., Zou, Y., & Bao, C. (2021). Automated Container Terminal Production Operation and Optimization via an AdaBoost-Based Digital Twin Framework. *Journal of Advanced Transportation*, *2021*. https://doi.org/10.1155/2021/1936764

Liu, C. (2020). Iterative heuristic for simultaneous allocations of berths, quay cranes, and yards under practical situations. *Transportation Research Part E: Logistics and Transportation Review*, *133*. https://doi.org/10.1016/j.tre.2019.11.008

Liu, C., Zheng, L., & Zhang, C. (2016). Behavior perception-based disruption models for berth allocation and quay crane assignment problems. *Computers and Industrial Engineering*, *97*, 258–275. https://doi.org/10.1016/j.cie.2016.04.008

Longo, F. (2019). Sustainability in logistic hubs: A decision support system for investigating green practices at container terminals. *International Journal of Simulation and Process Modelling*, *14*(3), 234–250. https://doi.org/10.1504/IJSPM.2019.101008

Lu, C., Zeng, B., & Liu, S. (2020). A Study on the Block Relocation Problem: Lower Bound Derivations and Strong Formulations. *IEEE Transactions on Automation Science and Engineering*, *17*(4), 1829–1853. https://doi.org/10.1109/TASE.2020.2979868

Lu, H., & Wang, S. (2019). A study on multi-ASC scheduling method of automated container terminals based on graph theory. *Computers and Industrial Engineering*, *129*, 404–416. https://doi.org/10.1016/j.cie.2019.01.050

Lu, H., Zhen, H., Huang, Y., & Yan, W. (2013). Assembly sequence planning of quayside container crane based on improved immune algorithm. *Journal of Applied Sciences*, *13*(22), 4922–4928. https://doi.org/10.3923/jas.2013.4922.4928

Lu, Y. (2021). The Three-Stage Integrated Optimization of Automated Container

Terminal Scheduling Based on Improved Genetic Algorithm. *Mathematical Problems in Engineering, 2021*. https://doi.org/10.1155/2021/6792137

Lujan, E., Vergara, E., Rodriguez-Melquiades, J., Jiménez-Carrión, M., Sabino-Escobar, C., & Gutierrez, F. (2021). A fuzzy optimization model for the berth allocation problem and quay crane allocation problem(BAP + QCAP) with n quays. *Journal of Marine Science and Engineering*, *9*(2), 1–15. https://doi.org/10.3390/jmse9020152

Luna, J. H., Mar-Ortiz, J., Gracia, M. D., & Morales-Ramírez, D. (2018). An efficiency analysis of cargo-handling operations at container terminals. *Maritime Economics and Logistics*, *20*(2), 190–210. https://doi.org/10.1057/s41278-017-0074-8

Lunin, A., & Glock, C. H. (2021). Systematic review of Kinect-based solutions for physical risk assessment in manual materials handling in industrial and laboratory environments. *Computers and Industrial Engineering*, *162*. https://doi.org/10.1016/j.cie.2021.107660

Ma, H.-L., Wong, C. W.-H., Leung, L. C., & Chung, S.-H. (2020). Facility sharing in business-to-business model: A real case study for container terminal operators in Hong Kong port. *International Journal of Production Economics*, *221*. https://doi.org/10.1016/j.ijpe.2019.09.004

Madsen, P. P. (2015). *Soft Computing*. https://slideplayer.com/slide/4180900/

Maloni, M., & Jackson, E. C. (2005). North American container port capacity: A literature review. *Transportation Journal*, *44*(2), 16–36. https://www.scopus.com/inward/record.uri?eid=2-s2.0-21544447808&partnerID=40&md5=3b3b5bfea4d084a6d09a371296072fbc

Mar-Ortiz, J., Castillo-García, N., & Gracia, M. D. (2019). A decision support system for a capacity management problem at a container terminal. *International Journal* *of Production Economics*. https://doi.org/10.1016/j.ijpe.2019.09.023

Mi, C., Huang, Y., Fu, C., Zhang, Z., & Postolache, O. (2021). Vision-Based Measurement: Actualities and Developing Trends in Automated Container Terminals. *IEEE Instrumentation and Measurement Magazine*, *24*(4), 65–76. https://doi.org/10.1109/MIM.2021.9448257

Mishra, N., Roy, D., & Van Ommeren, J. K. (2017). A stochastic model for interterminal container transportation. *Transportation Science*, *51*(1), 67–87. https://doi.org/10.1287/trsc.2016.0726

Moini, N., Boile, M., Theofanis, S., & Laventhal, W. (2012). Estimating the determinant factors of container dwell times at seaports. *Maritime Economics and Logistics*, *14*(2), 162–177. https://doi.org/10.1057/mel.2012.3

Monaco, M. F., Sammarra, M., & Sorrentino, G. (2014). The terminal-oriented ship stowage planning problem. *European Journal of Operational Research*, *239*(1), 256–265. https://doi.org/10.1016/j.ejor.2014.05.030

Muravev, D., Rakhmangulov, A., Hu, H., & Zhou, H. (2019). The introduction to system dynamics approach to operational effciency and sustainability of dry port's main parameters. *Sustainability*, *11*(8). https://doi.org/10.3390/su11082413

Nabeshima, Y., Kiryu, T., & Arakaki, M. (1978). HITACHI AUTOMATED CONTAINER TERMINAL SYSTEM. *Hitachi Review*, *27*(6), 295–300. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0018020280&partnerID=40&md5=7e25aa3babfe2e68e530752ca58432ee

Nasution, N. K. G., Jin, X., & Singgih, I. K. (2022). Classifying games in container terminal logistics field: A systematic review. *Entertainment Computing*, *40*. https://doi.org/10.1016/j.entcom.2021.100465

Navis. (2014). *Navis N4 XPS Advanced Vessel Planning and Control*.

Navis. (2019). *WHAT’S NEW IN N4 RELEASE 3.8*. *June*, 1–9.

Negenborn, R. (2014). Analysis for Inter Terminal Transportation demand scenarios for the Maasvlakte I and II in 2030. *Delft University of Technology*. http://inter-terminal.net/itt-reports/ITT - D3.1 - Evaluation - Cost and benefits.pdf

Nellen, N., Grafelmann, M., Ziegenbein, J., Lange, A.-K., Kreutzfeldt, J., & Jahn, C. (2020). Literature Classification on Container Transport Systems for Inter-terminal Transportation. *LDIC*, 52–61. https://doi.org/10.1007/978-3-030-44783-0_5

Nieuwkoop, F., Corman, F., Negenborn, R. R., Duinkerken, M. B., Van Schuylenburg, M., & Lodewijks, G. (2014). Decision support for vehicle configuration determination in Inter Terminal Transport system design. *Proceedings of the 11th IEEE International Conference on Networking, Sensing and Control, ICNSC 2014*, 613–618. https://doi.org/10.1109/ICNSC.2014.6819696

Nishimura, E., Imai, A., & Papadimitriou, S. (2001). Berth allocation planning in the public berth system by genetic algorithms. *European Journal of Operational Research*, *131*(2), 282–292. https://doi.org/10.1016/S0377-2217(00)00128-4

Niu, B., Liu, Q., Wang, Z., Tan, L., & Li, L. (2021). Multi-objective bacterial colony optimization algorithm for integrated container terminal scheduling problem. *Natural Computing*, *20*(1), 89–104. https://doi.org/10.1007/s11047-019-09781-3

Notteboom, T., Pallis, A., & Rodrigue, J.-P. (2022). *Port Economics, Management and Policy*. https://doi.org/doi.org/10.4324/9780429318184

Notteboom, T., Parola, F., & Satta, G. (2014). *Partim transshipment volumes*.

OECD & EUIPO. (2021). *Misuse of Containerized Maritime Shipping in the Global*

Trade of Counterfeits. https://doi.org/10.1787/e39d8939-en

Pacino, D. (2018). Crane Intensity and Block Stowage Strategies in Stowage Planning. *International Conference on Computational Logistics*, *11184*, 191–206. https://doi.org/10.1007/978-3-030-00898-7

Parreño, F., Pacino, D., & Alvarez-Valdes, R. (2016). A GRASP algorithm for the container stowage slot planning problem. *Transportation Research Part E: Logistics and Transportation Review*, *94*, 141–157. https://doi.org/10.1016/j.tre.2016.07.011

Perera, H. N., Fahimnia, B., & Tokar, T. (2020). Inventory and ordering decisions: a systematic review on research driven through behavioral experiments. *International Journal of Operations and Production Management*, *40*(7–8), 997–1039. https://doi.org/10.1108/IJOPM-05-2019-0339

Perera, H. N., Hurley, J., Fahimnia, B., & Reisi, M. (2019). The human factor in supply chain forecasting: A systematic review. *European Journal of Operational Research*, *274*(2), 574–600. https://doi.org/10.1016/j.ejor.2018.10.028

Perera, H. N., & Perera, H. Y. R. (2022). Applications of Pixel Oriented Mobility Modelling in Transport & Logistics. In M. Freitag, A. Kinra, H. Kotzab, & N. Megow (Eds.), *Dynamics in Logistics* (pp. 337–348). Springer International Publishing.

Petering, M. E. H. (2011). Decision support for yard capacity, fleet composition, truck substitutability, and scalability issues at seaport container terminals. *Transportation Research Part E: Logistics and Transportation Review*, *47*(1), 85–103. https://doi.org/10.1016/j.tre.2010.07.007

Phruksaphanrat, B., & Tanthatemee, T. (2012). Fuzzy inventory control system for uncertain demand and supply. *Lecture Notes in Engineering and Computer Science*, *2196*(March 2012), 1224–1229.

Raman, H., & Ramkumar, G. (1988). Simulation model for analysis of waiting time of ships and berth occupancy in ports. *Journal of the Institution of Engineers (India), Part MR: Marine Engineering Division*, *68* pt *2*, 35–40. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0024001173&partnerID=40&md5=ce69c5421785cf8952742c9c9d3fd00d

Reefke, H. (2010). *Simulation of container traffic flows at a metropolitan seaport: Vol. 46 LNBI* (pp. 420–431). Springer Verlag. https://doi.org/10.1007/978-3-642-12494-5_37

Rego, C., & Roucairol, C. (1995). Using Tabu search for solving a dynamic multi-terminal truck dispatching problem. *European Journal of Operational Research*, *83*(2), 411–429. https://doi.org/10.1016/0377-2217(95)00016-J

Ren, W. (2012). Yard crane scheduling with time window and dynamic demand strategy based on resource sharing. *International Journal of Digital Content Technology and Its Applications*, *6*(8), 213–221. https://doi.org/10.4156/jdcta.vol6.issue8.25

Rodrigues, F., & Agra, A. (2021). An exact robust approach for the integrated berth allocation and quay crane scheduling problem under uncertain arrival times. *European Journal of Operational Research*. https://doi.org/10.1016/j.ejor.2021.03.016

Rodrigues, F., & Agra, A. (2022). Berth allocation and quay crane assignment/scheduling problem under uncertainty: A survey. *European Journal of Operational Research*. https://doi.org/10.1016/j.ejor.2021.12.040

Safaeian, M., Etebari, F., & Vahdani, B. (2021). An integrated quay crane assignment and scheduling problem with several contractors in container terminals. *Scientia Iranica*, *28*(2), 1030–1048. https://doi.org/10.24200/sci.2019.53338.3191

Saginaw II, D. J., & Perakis, A. N. (1989). Decision support system for containership stowage planning. *Marine Technology and SNAME News*, *26*(1), 47–61. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0024479859&partnerID=40&md5=b1e5d28da39d1282a39cba366f7bc4b9

Salido, M. A., Rodriguez-Molins, M., & Barber, F. (2011). Integrated intelligent techniques for remarshaling and berthing in maritime terminals. *Advanced Engineering Informatics*, *25*(3), 435–451. https://doi.org/10.1016/j.aei.2010.10.001

Schepler, X., Balev, S., Michel, S., & Sanlaville, É. (2017). Global planning in a multi-terminal and multi-modal maritime container port. *Transportation Research Part E: Logistics and Transportation Review*, *100*, 38–62. https://doi.org/10.1016/j.tre.2016.12.002

Schroer, H. J. L., Corman, F., Duinkerken, M. B., Negenborn, R. R., & Lodewijks, G. (2015). *Evaluation of inter terminal transport configurations at Rotterdam Maasvlakte using discrete event simulation* (T. A., Y. L., D. S.Y., & R. I.O. (eds.); Vols 2015-Janua, pp. 1771–1782). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/WSC.2014.7020026

Seth, S., & Feng, Q. (2020). Assessment of port efficiency using stepwise selection and window analysis in data envelopment analysis. *Maritime Economics and Logistics*, *22*(4), 536–561. https://doi.org/10.1057/s41278-020-00155-6

Sha, M., Notteboom, T., Zhang, T., Zhou, X., & Qin, T. (2021). Simulation model to determine ratios between quay, yard and intra-terminal transfer equipment in an integrated container handling system. *Journal of International Logistics and Trade*, *19*(1), 1–18. https://doi.org/10.24006/JILT.2021.19.1.001

Shang, X. T., Cao, J. X., & Ren, J. (2016). A robust optimization approach to the integrated berth allocation and quay crane assignment problem. *Transportation Research Part E: Logistics and Transportation Review*, *94*, 44–65. https://doi.org/10.1016/j.tre.2016.06.011

Shields, J. J. (1984). CONTAINERSHIP STOWAGE: A COMPUTER-AIDED PREPLANNING SYSTEM. *Marine Technology*, *21*(4), 370–383. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0021513351&partnerID=40&md5=f5abd046469dfd83d60442f8eedbe3bb

Silberholz, M. B., Golden, B. L., & Baker, E. K. (1991). Using simulation to study the impact of work rules on productivity at marine container terminals. *Computers and Operations Research*, *18*(5), 433–452. https://doi.org/10.1016/0305-0548(91)90020-R

Sislioglu, M., Celik, M., & Ozkaynak, S. (2019). A simulation model proposal to improve the productivity of container terminal operations through investment alternatives. *Maritime Policy and Management*, *46*(2), 156–177. https://doi.org/10.1080/03088839.2018.1481544

SLPA. (2015). *Sri Lanka Ports Authority Annual Report 2015*.

SLPA. (2016). Forging Ahead. *Manufacturing Engineer*, *69*(1), 38–39. https://doi.org/10.1049/me:19900025

Song, X., Jin, J. G., & Hu, H. (2021). Planning shuttle vessel operations in large container terminals based on waterside congestion cases. *Maritime Policy and Management*, *48*(7), 988–1009. https://doi.org/10.1080/03088839.2020.1719443

Spruijt, A., Van Duin, R., & Rieck, F. (2017). *Towards an autonomous system for handling inter-terminal container transport*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85050103314&partnerID=40&md5=023d8b5f076d8550da0970b01c0c1938

Stahlbock, R, & Voß, S. (2007). Operations research at container terminals: A literature update. *OR Spectrum*, *30*(1), 1–52. https://doi.org/10.1007/s00291-007-0100-9

Stahlbock, Robert, & Voß, S. (2007). Operations research at container terminals: A literature update. *OR Spectrum*, *30*(1), 1–52. https://doi.org/10.1007/s00291-007-0100-9

Steenken, D., Voß, S., & Stahlbock, R. (2004). Container terminal operation and operations research - A classification and literature review. *OR Spectrum*, *26*(1), 3–49. https://doi.org/10.1007/s00291-003-0157-z

Sun, D., Tang, L., Baldacci, R., & Lim, A. (2021). An exact algorithm for the unidirectional quay crane scheduling problem with vessel stability. *European Journal of Operational Research*, *291*(1), 271–283. https://doi.org/10.1016/j.ejor.2020.09.033

Svitek, M., Kosheleva, O., & Kreinovich, V. (2021). *As Complexity Rises, Meaningful Statements Lose Precision - but Why ?*

Tan, C., Yan, W., & Yue, J. (2021). Quay crane scheduling in automated container terminal for the trade-off between operation efficiency and energy consumption. *Advanced Engineering Informatics*, *48*. https://doi.org/10.1016/j.aei.2021.101285

Tan, Z., Zhang, Q., Yuan, Y., & Jin, Y. (2022). A decision method on yard cranes transformation and deployment in green ports. *International Transactions in Operational Research*, *29*(1), 323–346. https://doi.org/10.1111/itor.13027

Tierney, K, Voß, S., & Stahlbock, R. (2014). A mathematical model of inter-terminal transportation. *European Journal of Operational Research*, *235*(2), 448–460. https://doi.org/10.1016/j.ejor.2013.07.007

Tierney, Kevin, Voß, S., & Stahlbock, R. (2014). A mathematical model of inter-terminal transportation. *European Journal of Operational Research*, *235*(2), 448–460. https://doi.org/10.1016/j.ejor.2013.07.007

Ting, S.-C., Wang, J.-S., Kao, S.-L., & Pitty, F. M. (2010). Categorized stacking models for import containers in port container terminals. *Maritime Economics and Logistics*, *12*(2), 162–177. https://doi.org/10.1057/mel.2010.4

Torkjazi, M., Huynh, N., & Shiri, S. (2018). Truck appointment systems considering impact to drayage truck tours. *Transportation Research Part E: Logistics and Transportation Review*, *116*, 208–228. https://doi.org/10.1016/j.tre.2018.06.003

Uesugi, M., Irohara, T., & Yoshimoto, K. (2001). A Study on Vehicle Routing Scheduling Problem under Limited Number of Berths. *Nihon Kikai Gakkai Ronbunshu, C Hen/Transactions of the Japan Society of Mechanical Engineers, Part C*, *67*(662), 3345–3350. https://doi.org/10.1299/kikaic.67.3345

UNCTAD. (2019). *The Review of Maritime Transport 2019* (Issue October). https://unctad.org/en/PublicationsLibrary/rmt2019_en.pdf

UNCTAD. (2020). *Review of Maritime Transport 2020*. https://unctad.org/system/files/official-document/rmt2020_en.pdf

UNCTAD. (2021). *Review of Maritime Report*. http://unctad.org/en/PublicationsLibrary/rmt2015_en.pdf

Unsal, O., & Oguz, C. (2013). Constraint programming approach to quay crane scheduling problem. *Transportation Research Part E: Logistics and Transportation Review*, *59*, 108–122. https://doi.org/10.1016/j.tre.2013.08.006

Ursavas, E. (2014). A decision support system for quayside operations in a container terminal. *Decision Support Systems*, *59*(1), 312–324. https://doi.org/10.1016/j.dss.2014.01.003

Ursavas, E. (2017). Crane allocation with stability considerations. *Maritime Economics and Logistics*, *19*(2), 379–401. https://doi.org/10.1057/mel.2015.35

Vahdani, B., Mansour, F., Soltani, M., & Veysmoradi, D. (2019). Bi-objective optimization for integrating quay crane and internal truck assignment with challenges of trucks sharing. *Knowledge-Based Systems*, *163*, 675–692. https://doi.org/10.1016/j.knosys.2018.09.025

van-Eck, N. J., & Waltman, L. (2014). Measuring Scholarly Impact. In *Measuring Scholarly Impact*. https://doi.org/10.1007/978-3-319-10377-8

van Hee, K. M., & Wijbrands, R. J. (1988). Decision support system for container terminal planning. *European Journal of Operational Research*, *34*(3), 262–272. https://doi.org/10.1016/0377-2217(88)90147-6

Vis, I. F. A., & Carlo, H. J. (2010). Sequencing two cooperating automated stacking cranes in a container terminal. *Transportation Science*, *44*(2), 169–182. https://doi.org/10.1287/trsc.1090.0298

Vis, I. F. A., & De Koster, R. (2003). Transshipment of containers at a container terminal: An overview. *European Journal of Operational Research*, *147*(1), 1–16. https://doi.org/10.1016/S0377-2217(02)00293-X

Wan, Y.-W., Liu, J., & Tsai, P.-C. (2009). The assignment of storage locations to containers for a container stack. *Naval Research Logistics*, *56*(8), 699–713. https://doi.org/10.1002/nav.20373

Wang, G. W. Y., Pallis, A. A., & Notteboom, T. E. (2014). Incentives in cruise terminal concession contracts. *Research in Transportation Business and Management*, *13*, 36–42. https://doi.org/10.1016/j.rtbm.2014.11.002

Wasesa, M., Ramadhan, F. I., Nita, A., Belgiawan, P. F., & Mayangsari, L. (2021). Impact of overbooking reservation mechanism on container terminal's operational performance and greenhouse gas emissions. *Asian Journal of Shipping and Logistics*, *37*(2), 140–148. https://doi.org/10.1016/j.ajsl.2021.01.002

Weerasinghe, B. A., Perera, H. N., & Kießner, P. (2021). *Planning decision alterations and container terminal efficiency*. https://doi.org/10.1108/MABR-04-2021-0035

Weerasinghe, B. A., Perera, H. N., & Kießner, P. (2022). *Planning decision alterations and container terminal efficiency*. https://doi.org/https://doi.org/10.1108/MABR-04-2021-0035

Weerasinghe, B., Perera, H. N., & Kiessner, P. (2021). *Effects of Altering Planning Decisions on The Efficiency of Container Terminals*. 1–4.

Wilson, I. D., & Roach, P. A. (1999). Principles of combinatorial optimization applied to container-ship stowage planning. *Journal of Heuristics*, *5*(4), 403–418. https://doi.org/10.1023/A:1009680305670

Xiang, X., & Liu, C. (2021). An almost robust optimization model for integrated berth allocation and quay crane assignment problem. *Omega (United Kingdom)*, *104*. https://doi.org/10.1016/j.omega.2021.102455

Xiao, Q., Li, F., Ge, X., & Yu, X. (2022). *Research on scheduling optimization of internal trucks for inter-terminal transportation*. *2277*(1). https://doi.org/10.1088/1742-6596/2277/1/012005

Xiao, Z., Xia, S., Gong, K., & Li, D. (2012). The trapezoidal fuzzy soft set and its application in MCDM. *Applied Mathematical Modelling*, *36*(12), 5844–5855. https://doi.org/10.1016/j.apm.2012.01.036

Xin, J., Negenborn, R. R., & Lodewijks, G. (2014). Energy-aware control for automated container terminals using integrated flow shop scheduling and optimal control. *Transportation Research Part C: Emerging Technologies*, *44*, 214–230. https://doi.org/10.1016/j.trc.2014.03.014

Xu, B., Jie, D., Li, J., Yang, Y., Wen, F., & Song, H. (2021). Integrated scheduling optimization of U-shaped automated container terminal under loading and unloading mode. *Computers and Industrial Engineering*, *162*. https://doi.org/10.1016/j.cie.2021.107695

Xu, B., Liu, X., Yang, Y., Li, J., & Postolache, O. (2021). Optimization for a multi-constraint truck appointment system considering morning and evening peak congestion. *Sustainability (Switzerland)*, *13*(3), 1–19. https://doi.org/10.3390/su13031181

Yang, C. H., Choi, Y. S., & Ha, T. Y. (2004). Simulation-based performance evaluation of transport vehicles at automated container terminals. *OR Spectrum*, *26*(2), 149–170. https://doi.org/10.1007/s00291-003-0151-5

Yu, H., Ge, Y. E., Chen, J., Luo, L., Tan, C., & Liu, D. (2017). CO2 emission evaluation of yard tractors during loading at container terminals. *Transportation Research Part D: Transport and Environment*, *53*, 17–36. https://doi.org/10.1016/J.TRD.2017.03.014

Yu, J., Voß, S., & Song, X. (2022). Multi-objective optimization of daily use of shore side electricity integrated with quayside operation. *Journal of Cleaner Production*, *351*. https://doi.org/10.1016/j.jclepro.2022.131406

Zadeh, L. A. (1965). Fuzzy sets. *Journal of Information and Control*, *8*, 338--353. https://doi.org/10.1061/9780784413616.194

Zeng, Q., Feng, Y., & Chen, Z. (2017). Optimizing berth allocation and storage space in direct transshipment operations at container terminals oa. *Maritime Economics and Logistics*, *19*(3), 474–503. https://doi.org/10.1057/mel.2016.2

Zeng, Q., & Yang, Z. (2009). Integrating simulation and optimization to schedule loading operations in container terminals. *Computers and Operations Research*, *36*(6), 1935–1944. https://doi.org/10.1016/j.cor.2008.06.010

Zhang, C., Zheng, L., Zhang, Z., Shi, L., & Armstrong, A. J. (2010). The allocation of berths and quay cranes by using a sub-gradient optimization technique. *Computers and Industrial Engineering*, *58*(1), 40–50. https://doi.org/10.1016/j.cie.2009.08.002

Zhang, W.-Y., Lin, Y., Ji, Z.-S., & Zhang, G.-F. (2008). Review of containership stowage plans for full routes. *Journal of Marine Science and Application*, *7*(4), 278–285. https://doi.org/10.1007/s11804-008-7087-8

Zhang, Y., Rong, Z., & Liu, Z.-X. (2014). The integrated scheduling problem in container terminal with dual-cycle operation. *International Journal of Simulation Modelling*, *13*(3), 335–347. https://doi.org/10.2507/IJSIMM13(3)CO12

Zhao, W., & Goodchild, A. V. (2013). Using the truck appointment system to improve yard efficiency in container terminals. *Maritime Economics and Logistics*, *15*(1), 101–119. https://doi.org/10.1057/mel.2012.23

Zhen, L, Sun, Q., Zhang, W., Wang, K., & Yi, W. (2021). Column generation for low carbon berth allocation under uncertainty. *Journal of the Operational Research Society*, *72*(10), 2225–2240. https://doi.org/10.1080/01605682.2020.1776168

Zhen, Lu, Xu, Z., Wang, K., & Ding, Y. (2016). Multi-period yard template planning in container terminals. *Transportation Research Part B: Methodological*, *93*, 700–719. https://doi.org/10.1016/j.trb.2015.12.006

Zheng, F., Huang, J., Liu, M., & Chu, F. (2016). *Port truck scheduling on a dedicated transportation route at a container terminal*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85013845809&partnerID=40&md5=78f5644eff2f0fb72710425d8edfdd1f

Zheng, H., Negenborn, R. R., & Lodewijks, G. (2014). Model Predictive Control of a waterborne AGV at the operational level. In *Maritime-Port Technology and Development* (pp. 99–108). CRC Press. https://www.scopus.com/inward/record.uri?eid=2-s2.0-

85130231010&partnerID=40&md5=0391a711c4bab5db502ce38b84e1b3fd

Zhou, C., Lee, B. K., & Li, H. (2020). Integrated optimization on yard crane scheduling and vehicle positioning at container yards. *Transportation Research Part E: Logistics and Transportation Review*, *138*. https://doi.org/10.1016/j.tre.2020.101966

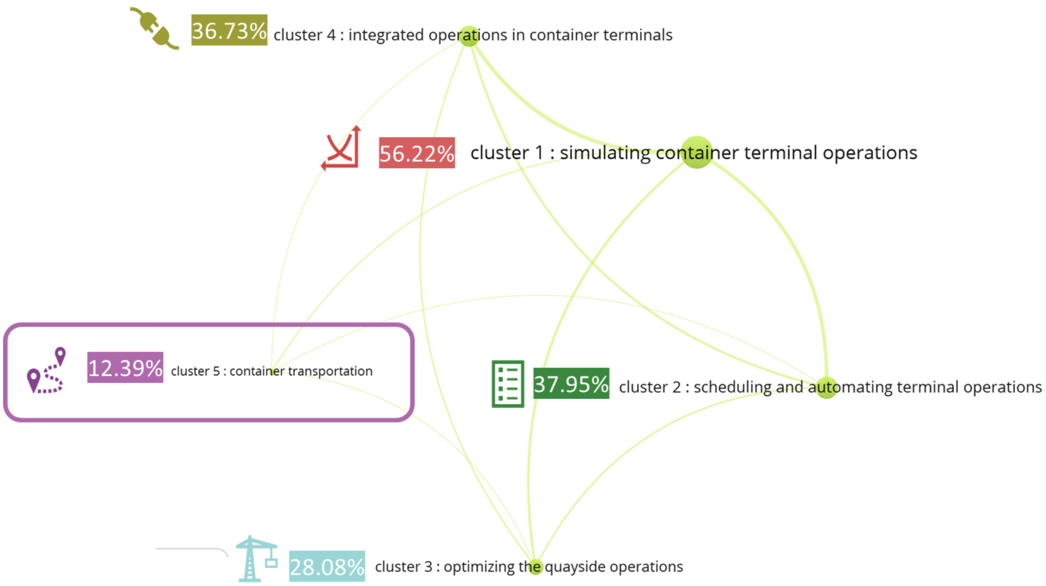
Zhou, C., Zhao, Q., & Li, H. (2021). Simulation optimization iteration approach on traffic integrated yard allocation problem in transshipment terminals. *Flexible Services and Manufacturing Journal*, *33*(3), 663–688. https://doi.org/10.1007/s10696-020-09393-5

Zhou, Y., Wang, W., Song, X., & Guo, Z. (2016). Simulation-Based Optimization for Yard Design at Mega Container Terminal under Uncertainty. *Mathematical Problems in Engineering*, *2016*.

Zhuang, Z., Zhang, Z., Teng, H., Qin, W., & Fang, H. (2022). Optimization for integrated scheduling of intelligent handling equipment with bidirectional flows and limited buffers at automated container terminals. *Computers and Operations Research*, *145*. https://doi.org/10.1016/j.cor.2022.105863

Appendix

Appendix A – Connectivity between identified research clusters



Appendix B – FIS code in MATLAB

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[System]
Name='ITT_D3'
Type='mamdani'
Version=2.0
NumInputs=6
NumOutputs=3
NumRules=729
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'

[Input1]
Name='C_A'
Range=[0 180]
NumMFs=3
MF1='C_AL':'trapmf',[0 0 45 90]
MF2='C_AM':'trapmf',[45 67.5 112.5 135]
MF3='C_AH':'trapmf',[90 135 180 180]

[Input2]
Name='T_A'
```

```
Range=[0 200]
NumMFs=3
MF1='T_AL':'trapmf',[0 0 50 100]
MF2='T_AM':'trapmf',[50 75 125 150]
MF3='T_AH':'trapmf',[100 150 200 200]

[Input3]
Name='C_B'
Range=[0 150]
NumMFs=3
MF1='C_BL':'trapmf',[0 0 37.5 75]
MF2='C_BM':'trapmf',[37.5 56.25 93.75 112.5]
MF3='C_BH':'trapmf',[75 112.5 150 150]

[Input4]
Name='T_B'
Range=[0 200]
NumMFs=3
MF1='T_BL':'trapmf',[0 0 50 100]
MF2='T_BM':'trapmf',[50 75 125 150]
MF3='T_BH':'trapmf',[100 150 200 200]

[Input5]
Name='C_C'
Range=[0 120]
NumMFs=3
MF1='C_CL':'trapmf',[0 0 30 60]
MF2='C_CM':'trapmf',[30 45 75 90]
MF3='C_CH':'trapmf',[60 90 120 120]

[Input6]
Name='T_C'
Range=[0 200]
NumMFs=3
MF1='T_CL':'trapmf',[0 0 50 100]
MF2='T_CM':'trapmf',[50 75 125 150]
MF3='T_CH':'trapmf',[100 150 200 200]

[Output1]
Name='AL_A'
Range=[0 180]
NumMFs=3
MF1='AL_AL':'trapmf',[0 0 45 90]
MF2='AL_AM':'trapmf',[45 67.5 112.5 135]
MF3='AL_AH':'trapmf',[90 135 180 180]

[Output2]
Name='AL_B'
Range=[0 150]
NumMFs=3
MF1='AL_BL':'trapmf',[0 0 37.5 75]
MF2='AL_BM':'trapmf',[37.5 56.25 93.75 112.5]
MF3='AL_BH':'trapmf',[75 112.5 150 150]
```

```
[Output3]
Name='AL_C'
Range=[0 120]
NumMFs=3
MF1='AL_CL':'trapmf',[0 0 30 60]
MF2='AL_CM':'trapmf',[30 45 75 90]
MF3='AL_CH':'trapmf',[60 90 120 120]

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