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# Systematic Literature Review about the Possibilities for Optimizing Container Loading Tasks in the Case of Intermodal Container Terminals

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**Abstract:** The paper examines the optimization possibilities of container loading tasks regarding intermodal terminals. The research carried out is of great importance, as the role of these terminals is expected to increase in the future based on the forecasts. The research presents the operational characteristics of intermodal terminals well as applicable loading procedures and tools. It analyses current optimization approaches, including logistics and technological developments, using a systematic literature review (SLR). The article explores additional optimization opportunities offered by artificial intelligence, 5G networks and simulation models, which can contribute to more efficient loading tasks and provide higher-quality logistics services. The presented results represent a valuable contribution to the development of railway logistics systems from both a practical and a theoretical point of view.

**Keywords:** container optimization; container terminals; intermodal container terminals; systematic literature review

## 1 INTRODUCTION

This systematic literature review examines the methods applied so far for optimizing container loading, including simulation models, mathematical programming, and heuristic algorithms. Our aim is to provide a comprehensive overview of current approaches, highlighting their strengths, limitations, and interrelationships. Through our analysis, we seek to identify and explore research gaps and potential future directions for further improving container loading efficiency. This study may contribute to the development and implementation of new optimization solutions, as well as to future research topics.

## 2 BASIC CHARACTERISTICS OF INTERMODAL CONTAINER TERMINALS

Intermodal container terminals are essential components of international transportation and global supply chains, as they ensure seamless transitions between various modes of transport, such as rail, road, and maritime shipping. The efficiency and optimization of container loading are becoming increasingly important for improving terminal operations, as they directly affect costs, transit times, and service quality. The goal of container loading is to ensure fast, cost-effective, and safe handling of containers between different modes of transportation. In addition to transshipment, terminals are also involved in warehousing, customs clearance, repackaging, and the documentation of these processes. The transfer of goods typically occurs between road, rail, and waterborne vehicles, but air transport can also be part of the process. Terminals play a vital role in freight forwarding, enabling the most cost-efficient transportation of goods. They are key elements of the global supply chain, facilitating the efficient movement of containers.

The role of container terminals is continuously growing due to increasing freight transport demands and stricter environmental regulations. Beyond transshipment, they offer various logistics services to enhance efficiency and provide high-quality customer service. Temporary storage and bonded warehouses offer financial security for customers while enabling faster customs clearance [1-4].

The two most common types of intermodal container terminals are rail terminals and container terminals, generally classified based on the number of available modes of transport.

The main categories are:

- Unimodal: One primary mode of transport, typically road.
- Bimodal: Two transport modes, usually road and rail.
- Multimodal: Three or more transport modes.

Beyond these types, the evaluation of terminals can also consider the following key characteristics:

- Ownership structure: Public, private, or mixed.
- Size: The facility's area (e.g., in hectares).
- Cargo handling capacity: The capacity of transshipment equipment and storage areas.
- Traffic volume: The amount of goods handled (in tons, combined transport units), the number of customers, transport routes, and cargo composition [3, 6].

## 3 SYSTEMATIC LITERATURE REVIEW

The research followed a structured set of steps (Fig. 1) to achieve its objectives, guaranteeing a high-quality study and preventing the loss of scientific information [7-9].

This analysis includes an extensive search and evaluation of publications in English.

The process of conducting a systematic literature analysis involves the following steps:

1) Motivation
2) Define research questions
3) Define keywords
4) Literature analysis
5) Selection of relevant literature
6) Systematic review
7) Define research gap.

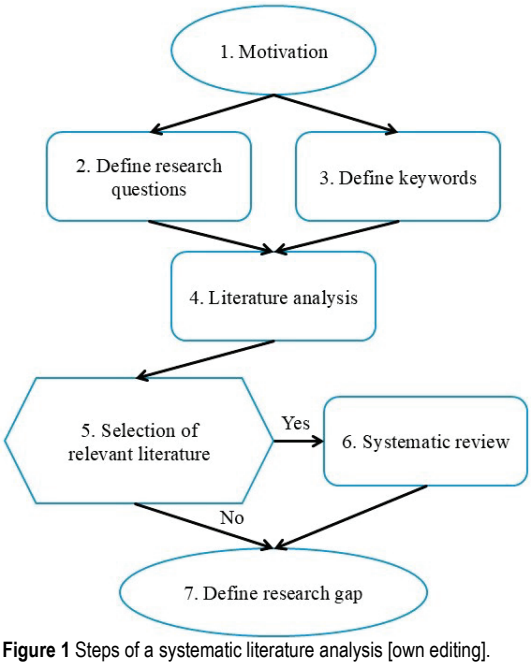



**Figure 1** Steps of a systematic literature analysis [own editing].

### 3.1 Motivation

The purpose of this systematic literature review is to collect and analyse various studies and methods related to the optimization of container loading in intermodal container terminals by using Scopus and google scholar database.

The acquired knowledge, including methods, opportunities, and existing ideas, will support future research in the field and help identify a research gap.

### 3.2 Research Questions

The aim of the research is to determine what optimization methods are used to improve container loading in intermodal container terminals. The key questions posed in this systematic review are as follows:

- What mathematical models, algorithms, and simulations can be applied to optimize container loading?
- What benefits do the applied optimization methods offer, and how do they impact costs, time savings, and terminal performance?
- What scientific research has been published in this field between the 2000-2024.

### 3.3 Define Keywords

The primary objective of this step is to define the keywords and their respective combinations. Academic papers were selected through the use of "AND" logical combinations. The keywords are Container, container terminal, optimization, loading, unloading, method.

### 3.4 Literature Analysis

In the fourth step, the actual literature analysis is conducted. Two academic research databases were utilized in the current study. We used the Scopus and Google Scholar databases during the research; however, the final step was not performed on Google Scholar.

### 3.5 Selection of Relevant literature

In the fifth step, the relevant literature is selected based on the findings from the literature review. After reviewing the results, and selecting and reading the pertinent publications, the focus shifts to defining the primary research direction.

During a systematic literature search, the areas are narrowed down based on the topic, research area and language. In the current research, publications corresponding to the following categories were selected: research article, review article, chapter of book and minireview. The rest were not selected, and duplicates were removed.

The results of the analysis are shown in Fig. 2.

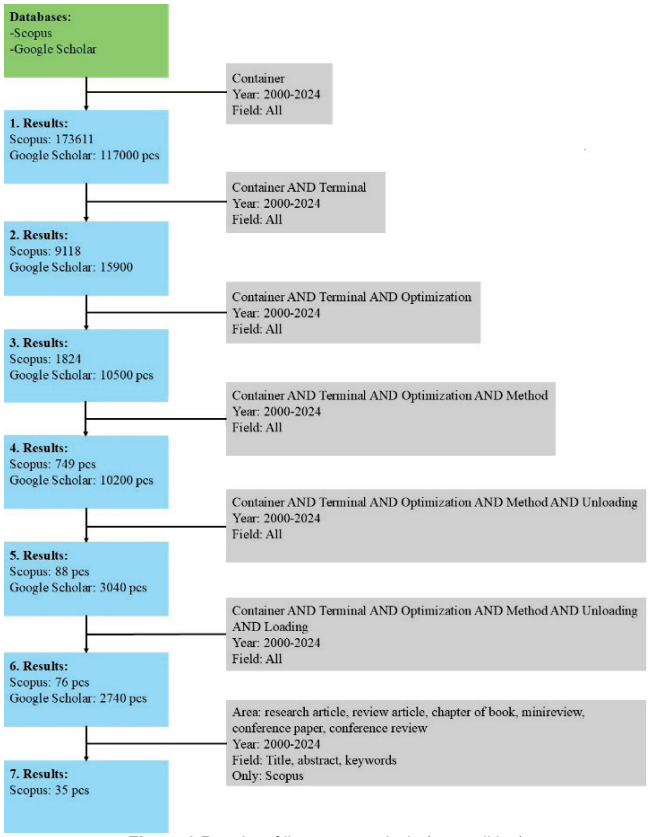



**Figure 2** Results of literature analysis (own editing)

### 3.6 Systematic Review and Define Research Gap

Following the systematic review, the relevant literature can be summarized in the following chapter 3.2, 3.3 and 3.4.

Upon reviewing all relevant publications and abstracts from the search results, a research gap can be systematically identified, as demonstrated in the present study.

## 4 RESEARCHED METHODS

Research on optimizing container loading in intermodal container terminals spans a wide range of methods. Key approaches include:

Mathematical Programming: Techniques such as linear and nonlinear programming help determine optimal resource allocation. Network analysis and graph theory also support the design of efficient handling strategies.

Simulation Modelling: Simulations, including agent-based models and Monte Carlo methods, help analyze container flow dynamics and test different operational scenarios for better decision-making.

Heuristic Algorithms: Methods like genetic algorithms, ant colony optimization, and tabu search offer fast, adaptable solutions for complex terminal operations, including layout planning and resource management.

Multi-Criteria Decision Support: Optimization often balances factors such as cost, time, and environmental impact. MCDA tools help identify solutions that align with multiple objectives.

Machine Learning: Recent trends show increasing use of techniques like reinforcement learning, neural networks, and predictive analytics. These tools enhance decisions by identifying operational patterns and adapting to dynamic terminal conditions.

The next section provides an overview of integrated scheduling methods for container handling and terminal operations, including the coordination of cranes, AGVs, and other equipment. It highlights two-stage modelling techniques, priority rule-based heuristics.

### 4.1 Equipment Coordination Strategies

Integrated Scheduling: Coordinating the operations of quay cranes, AGVs, and yard cranes is essential to minimize total completion time (makespan) and enhance terminal performance [10]. Integrated scheduling models often employ two-stage programming and rolling horizon procedures to optimize the routing and synchronization of equipment.

Priority Rule-Based Heuristics: These heuristics, when combined with genetic algorithms, are applied in general scheduling models to efficiently handle real-world challenges, such as those encountered in the Port of Hamburg.

It is important to note that gauge-changing terminals differ from other container terminals due to the necessity of transshipment from train to train for gauge conversion. However, the methods and container loading techniques should not be restricted solely to this aspect, as processes like container loading and scheduling can be applied universally.

The following section highlights that optimizing container loading reduces energy consumption and operational time. Genetic algorithms and simulation-optimization methods shorten loading time, while mixed-integer programming and adaptive heuristics enable efficient equipment scheduling, reducing vessel berthing and dwell times.

### 4.2 Container Loading and Handling

Optimizing container loading and handling is crucial for reducing energy consumption and operational time. A genetic algorithm can determine the optimal loading sequence, significantly reducing handling time, rearrangements, and energy consumption in rail-road intermodal container terminals. Similarly, minimizing container rearrangement through simulation-optimization methods can reduce operational costs by up to 7% [11-15].

For efficient container handling, terminals must coordinate and schedule various equipment such as transport vehicles, storage cranes, quay cranes, and automated guided vehicles (AGVs). Mixed-integer programming (MIP) models can optimize these operations, minimizing vessel berthing times and train dwell times. For large-scale problems, adaptive heuristic algorithms, which adjust the parameters of genetic algorithms, provide near-optimal solutions, improving both berthing and computation times [16-21].

The following section presents methods for modelling and solving container loading schedules. Mixed-integer programming enforces strict constraints, while heuristic approaches such as genetic algorithms provide fast, near-optimal solutions. Machine learning further refines these strategies by leveraging historical data, enhancing both flexibility and efficiency.

### 4.3 Key Approaches and Models

- Mixed-Integer Programming (MIP) Models: These models mathematically formulate scheduling challenges while considering constraints related to the coordinated operation of various equipment. They are effective for small-scale problems, but heuristic methods are necessary for larger cases [21-26].
- Heuristic Algorithms: Various heuristic algorithms, such as multi-layer genetic algorithms (MLGA) and hybrid genetic-cuckoo optimization algorithms (HGCOA), help overcome computational difficulties and provide near-optimal solutions for large-scale problems. These algorithms dynamically adjust parameters to improve efficiency and solution quality [21-27].
- Simulated Annealing and Genetic Algorithms: Unique simulated annealing (SA) and genetic algorithms (GA) are used to balance solution quality and computational time, particularly in coordinated scheduling models that consider all terminal equipment collectively.
- Key optimization techniques and machine learning-driven approaches to solving the container relocation problem (CRP). Exact algorithms like Iterative Branch-and-Bound (IB&B) and heuristic methods such as Machine Learning-Driven Beam Search (MLBS). The integration of machine learning enhances decision-making efficiency, reducing computational complexity and improving optimization performance. Machine learning techniques, such as neural networks and random forests, assist in branch pruning and heuristic guidance, improving solution accuracy. These models analyse patterns from past data to refine optimization strategies dynamically [28, 29].

The unified application of methods from integrated scheduling to heuristic and machine learning based algorithms enables comprehensive optimization of container loading by reducing energy consumption, waiting times, and reshuffling operations. Mixed-integer programming ensures precise scheduling, while fast, near-optimal heuristics and metaheuristics support large-scale, real-time decision making. Machine learning–driven approaches continuously

refine these strategies, enhancing flexibility and overall terminal performance.

### 4.4 Detailed Reviewed Articles

Zheng et al. (2023) propose an integrated scheduling model to optimize container handling systems at container terminals, with a particular focus on green, low-carbon operations. As a first step, the study develops a Mixed-Integer Linear Programming (MILP) model that simultaneously considers the three main handling equipment types at container terminals: quay cranes (QC), yard trucks (YT), and yard cranes (YC). The model aims to minimize ship turnaround time and reduce energy consumption, ultimately improving terminal efficiency.

Since the MILP method becomes computationally intractable for larger problem sizes, the authors propose a genetic algorithm (GA). This approach utilizes a three-dimensional chromosome representation, encoding the QC loading sequence along with YT and YC assignments. The study details the algorithm's construction, including specialized order crossover, two-point crossover, and mutation operators, as well as a novel heuristic mutation procedure that facilitates finding high-quality solutions while avoiding local optima traps.

Computational experiments conducted on 25 benchmark instances validate the effectiveness of the proposed method, particularly for large-scale problems where traditional MILP solutions are either too time-consuming or entirely infeasible. Results indicate that the GA not only significantly reduces computation time but also produces competitive or even superior solutions for container terminal scheduling problems. This contributes substantially to green, energy-efficient operations at intermodal container terminals.

This study provides a valuable contribution to the literature on integrated scheduling problems in container terminals, demonstrating how traditional mathematical programming models can be adapted and combined with modern heuristic algorithms to tackle complex logistics challenges [30].

Homayouni et al. (2014) propose a genetic algorithm for optimizing the integrated scheduling of cranes, automated guided vehicles (AGVs), and split-platform automated storage/retrieval systems (SP-AS/RS) in automated container terminals. The study addresses operational challenges arising from increasing container throughput and the demand for faster vessel turnaround, emphasizing that coordinated scheduling offers significant efficiency gains over non-integrated approaches.

The paper first introduces the operating environment of automated container terminals, followed by a review of prior research, most of which focused only on partial scheduling for individual equipment types. In contrast, this study presents a fully integrated modelling approach, optimizing the sequence of crane operations, the assignment of AGVs to tasks, and the scheduling of storage platforms simultaneously.

The proposed genetic algorithm employs specialized operators, including crossover and mutation mechanisms designed to preserve the predefined sequence constraints of crane operations, ensuring solutions adhere to operational precedence conditions. Performance evaluations on various test cases demonstrate that the GA significantly outperforms traditional MIP models and simulated annealing algorithms, particularly for larger-scale problems. The study also explores the impact of a "stay-in-place" strategy for storage platforms, which reduces platform movement time and delays.

Overall, the work of Homayouni et al. makes a valuable contribution to research on integrated scheduling in automated container terminals, offering a robust metaheuristic approach for multi-equipment coordination optimization and enhancing terminal operational efficiency [31].

The next literature about Real-Time Optimization of the Container Relocation Problem (CRP)

The challenges of the Container Relocation Problem (CRP) arise when retrieving import containers in a predefined order from a container terminal. Often, blocking containers stacked above the target container need to be relocated, making the process non-productive and increasing operational costs. The time-consuming nature of CRP is further complicated by the random arrival of external trucks (ETs), making it difficult to predetermine the exact sequence of container retrievals. Additionally, CRP is classified as an NP-complete problem, which poses significant computational challenges for real-time optimization.

Several approaches have been proposed in the literature to optimize CRP, including integer programming models, exact algorithms such as A and branch-and-bound (B&B), and various heuristics. However, due to the exponential increase in problem complexity, these methods often fail to provide real-time solutions for large-scale CRP instances.

Unlike traditional approaches, Zhou and Zhang (2024) focus on optimizing individual operational rounds within the container terminal. By decomposing the problem into smaller subproblems, they develop a dynamic programming model, which derives a dynamic upper bound for the optimal solution and aims to minimize it. Their approach is built on three heuristic relocation rules:

- LL (Least-relocations-and-Lowest-precedence-gap) Rule: Minimizes future relocations by selecting a destination that preserves the container retrieval order while avoiding additional rehandling operations.
- MSS (Moving Ahead for Sequential Stack) Rule: Proactively relocates containers that may cause future blockages, leading to a more efficient stacking arrangement.
- FSS (Freeing up for Sequential Stack) Rule: Provides an alternative arrangement when only inverted stacking positions are available, reducing future operational costs.

By integrating these rules, the study introduces a new Sequential-Placement First Heuristic (SPFH) algorithm, which iteratively optimizes container retrieval sequences in a real-time operational environment, significantly reducing the number of relocations.

The study evaluates the proposed method on both small- and large-batch cases, demonstrating that SPFH achieves fast execution times and low relocation costs, making it well-suited for modern container terminals operating in real-time.

This study presents an innovative approach to the real-time optimization of the CRP. By leveraging a dynamic programming model and three heuristic rules, the method

successfully minimizes relocation operations and associated costs. The results indicate that SPFH offers a promising alternative to previous computationally intensive solutions, making a valuable contribution to the literature on CRP optimization [32].

The detailed case studies in Section 3.4 validate the effectiveness of the applied models on real terminal data, thereby substantiating the earlier general overviews with concrete metrics. By testing and comparing the novel algorithmic solutions such as the MILP-GA hybrid and the SPFH heuristic in real-world settings, this chapter clearly highlights the advantages of scalability and practical applicability.

## 5 SUMMARY AND RESULTS

The application of optimization methods in container loading offers several advantages:

- Cost Reduction: The use of simulation and mathematical models can lead to significant cost savings by reducing the necessary resources, such as cranes, loading personnel, and transportation time.
- Time Savings: Optimized container arrangements and reduced transit times increase terminal throughput and result in faster processes.
- Efficient Resource Allocation: The optimal allocation of resources enables terminals to operate more efficiently while ensuring the safe and rapid handling of containers.
- Reduction of Environmental Impact: Considering sustainability aspects, optimization methods can reduce carbon emissions and other environmental impacts.

Each applied optimization method contributes to improving the efficiency of container loading. However, the optimal solution depends on the specific characteristics of the terminal, such as size, the transportation modes used, and available resources. Integrated approaches that combine mathematical models, simulations, and heuristic algorithms often yield the best results, as they can adapt to dynamic environments.

Most studies confirm that optimizing container loading is a key factor in the competitiveness of terminals. However, the effectiveness and efficiency of applied methods depend on the specific characteristics of the terminal, and a combined approach is often required to achieve the best results. One of the biggest challenges is managing the dynamically changing logistics environment. Therefore, future research should focus on sustainability and the development of adaptive algorithms.

Future work should integrate digital-twin frameworks to mirror physical container yards in real time, enabling predictive optimization of stacking crane movements and reducing non-productive operations

### 5.1 Research Gap

Evidence derived from industry research and a systematic literature review demonstrates that although numerous examples exist for the application of the methods, scarcely any examples can be found that combine logistics simulation with machine learning in relation to the optimization of container loading tasks at container terminals.

Based on the previous, a possible research gap is the combined application of artificial intelligence combined with logistics simulation, supplemented by considering environmental conditions and traffic situations. The specified model could then provide information in a short period of time, for example based on the meteorological and traffic data, to determine optimal scheduling for loading operations, and it could prioritize more important shipments, while also prioritizing critical shipments to minimize delays.

Operators could influence the model's output with specific data to ensure the final results are as precise as possible. The rapid scheduling and optimized arrangement of container loading sequences could enhance terminal loading operations by providing up-to-date information and enabling swift recalculations in the event of unforeseen incidents, thereby reducing potential losses. Research should focus on integrating advanced AI techniques such as deep reinforcement learning to enable adaptive, data-driven loading decisions in real time. Finally, the fusion of human expertise with intelligent decision-support tools will be essential to address complex, uncertain scenarios and ensure robust, practical implementation.

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## 6 REFERENCES

[1] Woxenius, J., Andersson, E., Bärthel, F., Troche, G., Sommar, R., & Trouvè, J. (2004). *A Swedish intermodal transport service based on line-trains serving freight forwarders*. 10th WCTR '04, Istanbul, 4–8.

[2] Behrends, S., & Flodén, J. (2012). The effect of transhipment costs on the performance of intermodal linetrains. *Logistic Resources*, *4*, 127–136. https://doi.org/10.1007/s12159-012-0066-0

[3] European Court of Auditors. (2023). *Rail freight transport in the EU: Still not on the right track*. https://www.eca.europa.eu/Lists/ECADocuments/SR-2023-08/SR-2023-08_HU.pdf

[4] East West Intermodal Logistics Services. (n.d.). *Terminal*. https://eastwestil.com/terminal/

[5] Záhony-Port. (2024). *Záhony-Port EN 2024* [PDF document].

[6] Bokor, Z. (2005). Az intermodális logisztikai szolgáltatások helyzetének értékelése, fejlesztési lehetőségeinek feltárása. *Logisztika*, *10*(3), 22–64. (in Hungarian)

[7] Matyi, H., & Tamás, P. (2023). An innovative framework for quality assurance in logistics packaging. *Logistics*, *7*(4), 82. https://doi.org/10.3390/logistics7040082

[8] Kamarási, V., & Mogyorósy, G. (2015). Szisztematikus irodalmi áttekintések módszertana és jelentősége. Segítség a diagnosztikus és terápiás döntésekhez. *Orvosi Hetilap*, *156*(38), 1523–1531. (in Hungarian) https://doi.org/10.1556/650.2015.30255

[9] Rana, R. L., Adamashvili, N., & Tricase, C. (2022). The impact of blockchain technology adoption on tourism industry: A

systematic literature review. *Sustainability*, *14*(12), 7383. https://doi.org/10.3390/su14127383

[10] Zheng, Y., Xiao, Y., & Seo, Y. (2014). A tabu search algorithm for simultaneous machine/AGV scheduling problem. *International Journal of Production Research*, *52*, 5748–5763. https://doi.org/10.1080/00207543.2014.910628

[11] Wang, L., & Zhu, X. (2019). Container loading optimization in rail–truck intermodal terminals considering energy consumption. *Sustainability*. https://doi.org/10.3390/su11082383

[12] Dong, C., Boute, R., McKinnon, A., & Verelst, M. (2018). Investigating synchromodality from a supply chain perspective. *Transportation Research Part D: Transport and Environment*, *61*, 42–57. https://doi.org/10.1016/j.trd.2017.05.011

[13] Giusti, R., Iorfida, C., Li, Y., & Menerba, D. (2019). Sustainable and de-stressed international supply-chains through the SYNCHRO-NET approach. *Sustainability*, *11*, 1083. https://doi.org/10.3390/su11041083

[14] Ambra, T., Caris, A., & Macharis, C. (2018). Towards freight transport system unification: Reviewing and combining the advancements in the physical internet and synchromodal transport research. *International Journal of Production Research*, *47*, 1606–1623. https://doi.org/10.1080/00207543.2018.1494392

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

[16] Golias, M., Portal, I., Konur, D., Kaisar, E., & Kolomvos, G. (2014). Robust berth scheduling at marine container terminals via hierarchical optimization. *Computers & Operations Research*, *41*, 412–422. https://doi.org/10.1016/j.cor.2013.07.018

[17] Golias, M., Boile, M., Theofanis, S., & Efstathiou, C. (2010). The berth-scheduling problem. *Transportation Research Record: Journal of the Transportation Research Board*, *2166*, 20–27. https://doi.org/10.3141/2166-03

[18] Bierwirth, C., & Meisel, F. (2015). A follow-up survey of berth allocation and quay crane scheduling problems in container terminals. *European Journal of Operational Research*, *244*, 675–689. https://doi.org/10.1016/j.ejor.2014.12.030

[19] Iris, C., Christensen, J., Pacino, D., & Ropke, S. (2018). Flexible ship loading problem with transfer vehicle assignment and scheduling. *Transportation Research Part B: Methodological*, *111*, 113–134. https://doi.org/10.1016/j.trb.2018.03.009

[20] Chen, L., Bostel, N., Dejax, P., Cai, J., & Xi, L. (2007). A tabu search algorithm for the integrated scheduling problem of container handling systems in a maritime terminal. *European Journal of Operational Research*, *181*(1), 40–58. https://doi.org/10.1016/j.ejor.2006.06.033

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

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

[23] Kim, K. H., & Bae, J. W. (1999). A dispatching method for automated guided vehicles to minimize delays of containership operations. *International Journal of Management Science*, *5*(1), 1–25.

[24] Kim, K. H., & Bae, J. W. (2004). A look-ahead dispatching method for automated guided vehicles in automated port container terminal. *Transportation Science*, *38*(2), 224–234. https://doi.org/10.1287/trsc.1030.0082

[25] Luo, J., & Wu, Y. (2020). Scheduling of container-handling equipment during the loading process at an automated container terminal. *Computers & Industrial Engineering*, *149*, 106848. https://doi.org/10.1016/j.cie.2020.106848

[26] Zhang, X., Hong, Z., Xi, H., & Li, J. (2024). Optimizing multiple equipment scheduling for U-shaped automated container terminals considering loading and unloading operations. *Computer-Aided Civil and Infrastructure Engineering*. https://doi.org/10.1111/mice.13275

[27] Ting, C. J., & Wu, K. C. (2017). Optimizing container relocation operations at container yards with beam search. *Transportation Research Part E: Logistics and Transportation Review*, *103*, 17–31. https://doi.org/10.1016/j.tre.2017.04.010

[28] Zhang, C., Guan, H., Yuan, Y., Chen, W., & Wu, T. (2020). Machine learning-driven algorithms for the container relocation problem. *Transportation Research Part B: Methodological*, *139*, 102–131. https://doi.org/10.1016/j.trb.2020.05.017

[29] Lee, J., Choi, J., Koc, G., Sayin, G., & Seo, H. (2024). Incoming container schedule-aware container rearrangement planning based on reinforcement learning in container terminal. In *2024 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)* (pp. 1417–1421). https://doi.org/10.1109/IEEM62345.2024.10857158

[30] Zheng, Y., Xu, M., Wang, Z., & Xiao, Y. (2023). A genetic algorithm for integrated scheduling of container handling systems at container terminals from a low-carbon operations perspective. *Sustainability*. https://doi.org/10.3390/su15076035

[31] Homayouni, S., Tang, S., & 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

[32] Zhou, S., & Zhang, Q. (2024). Real-time batch optimization for the stochastic container relocation problem. *Applied Sciences*. https://doi.org/10.3390/app14062624

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