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AUTOMATION AND ROBOTICS FOR EFFICIENT CONTAINER HANDLING IN PORT TERMINAL: REVIEW

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Abstract: *This paper presents a review on optimizing container handling processes at maritime ports through the integration of automated guided vehicles, robotics solutions in the container yard, automatic inventory in the warehouse, equipment scheduling with speed optimization, etc. The research focuses on addressing the challenges associated with efficient loading and unloading operations at the terminal. The study explores the use of automated cranes, robotic systems, and intelligent control algorithms to enhance productivity and operational safety. The findings highlight the advancement of automation and robotics in port logistics, providing valuable insights for enhancing operational effectiveness, maximizing resource utilization, and minimizing energy consumption.*

Key words: *Automation, robotics, container handling, storage optimization, automated stacking cranes, robotic container handlers.*

1. INTRODUCTION

In recent years, the automation and optimization of container handling processes in maritime ports have gained attention due to the increasing global trade volumes and the consequent need for efficient and cost-effective operations [1]. To achieve these goals, advanced technologies such as automation, robotics, and intelligent systems are being implemented in container terminals through automated guided vehicles (AGVs), yard cranes, and quay cranes [3]. They offer the potential to enhance the efficiency, safety, and productivity of container handling operations [1]. Researchers have extensively studied various aspects of container handling optimization, including stowage planning [2] and scheduling of yard cranes [3] and AGVs [8]. Simulation and optimization techniques have been utilized for yard crane management [8]. Combinatorial optimization and mechanism design problems arising at container ports have been investigated [15]. Integrated scheduling of quay cranes and AGVs has been explored for automated container terminals [12]. Assignments and coordination of autonomous robots in container loading terminals have been studied [13]. Several approaches, such as branch-and-bound algorithms [15], bin-packing problem-based models [17], and integrated dispatching and scheduling with speed optimization [21], have been proposed for AGV routing and equipment scheduling.

The integration of automation and robotics technologies in container handling processes has the potential to address these challenges and optimize the overall operations [3]. By automating tasks such as container stacking, transportation, and stowage planning, port operators can achieve higher throughput, reduce labour costs, minimize errors, and improve overall operational efficiency.

Despite the potential benefits of automation and robotics in container handling, there are several challenges that need to be addressed. These challenges include optimizing the allocation and scheduling of resources such as yard cranes, AGVs, and quay cranes [3]. Additionally, efficient planning of container stowage in vessel bays is important for maximizing vessel capacity's utilization and minimizing the number and length of shifts [2] [5]. The complex nature of these problems,

combined with the large-scale and dynamic nature of port operations, requires the development of advanced optimization models, algorithms, and decision-support tools [1] [15].

This study aims to analyse existing approaches and models for optimizing container handling in automated terminals, evaluate the impact of automation and robotics on efficiency, and identify challenges in their integration, providing future research directions to address these challenges.

This research aims to address the following research questions:

Q1 - What are the existing approaches and models for optimizing container handling operations in automated container terminals?

Q2 - How much does the integration of automation and robotics technologies improve the efficiency and performance of container handling processes?

Q3 - What are the key challenges and, accordingly, what are the future research directions in the integration of automation and robotics technologies in container handling operations?

These research questions were chosen because they collectively cover important aspects of the integration of automation and robotics technologies in container handling operations. They provide a framework for examining current practices, assessing the benefits, and identifying challenges and future research directions. By addressing these research questions, the study aims to contribute to the existing knowledge in the field and provide insights for port operators, decision-makers, and researchers.

2. METHODOLOGY

To gather relevant information for this study, a systematic data collection and analysis process was implemented. This section outlines the data collection methods, databases utilized, keyword selection, rationale for choosing specific references, and the data analysis methods, offering an overview of the entire process.

To ensure a diverse range of perspectives and a comprehensive understanding of the subject matter, multiple data sources were considered. These included academic papers, conference proceedings, industry reports, and other relevant publications. This approach aimed to capture diverse viewpoints and offer a holistic analysis.

To access a wide array of academic publications, prominent databases were selected as the primary sources of data. The databases chosen, including Scopus, ScienceDirect, and Web of Science, are renowned for their vast academic literature coverage relevant to automation and robotics in container handling.

A systematic search strategy was developed, starting with the careful selection of appropriate keywords. The chosen keywords were crafted to reflect the essence of the research topic and align with the research questions and objectives. They encompassed relevant concepts such as "automation," "robotics," "container handling," and "port terminals," among others.

The search strategy involved using the selected keywords in combination with Boolean operators and search modifiers to refine and optimize the search results. This iterative process allowed for progressively narrowing down the search and retrieving more specific and relevant publications.

The search process commenced by inputting the initial set of keywords into the search interfaces of the selected databases. The initial search yielded a substantial number of results, reflecting the broad scope of the topic. For instance, an initial search using the keywords "automation" and "container handling" retrieved approximately 1,500 articles.

To further refine the search and focus on specific aspects, additional keywords were incorporated. For example, the inclusion of the keyword "efficiency" alongside the initial keywords resulted in a refined search that returned approximately 500 articles.

Throughout the search process, the obtained results were screened based on their titles and abstracts to assess their relevance to the research questions and objectives. Publications that demonstrated relevance and alignment with the research focus were selected for further evaluation.

The final set of references included in the study was chosen based on specific inclusion criteria. These criteria encompassed direct relevance to the research questions, focus on automation and robotics technologies in

container handling operations, and publication in the English language.

The selection of references was driven by the aim of obtaining a comprehensive understanding of the research topic. The inclusion of specific keywords and iterative refinement of the search strategy ensured the retrieval of relevant publications from the selected databases.

By refining the keyword search, the study yielded articles directly relevant to the research questions. This approach allowed for a more targeted exploration of the literature and facilitated a detailed analysis of the chosen references.

Through the systematic and purposeful selection of references, the study aimed to ensure a comprehensive coverage of the relevant literature and facilitate a robust analysis and synthesis of the collected data.

Once the relevant publications were identified and selected, a systematic approach was employed to analyse the collected data.

The selected articles were carefully reviewed and examined to extract key findings and insights related to the research objectives and questions. A qualitative analysis approach was adopted to gain a deeper understanding of the content and identify recurring themes, trends, and patterns across the literature.

The data analysis process involved several steps. Firstly, each selected article was thoroughly read to comprehend its context, methodology, and main findings. Secondly, relevant information, such as the employed approaches, models, technologies, benefits, challenges, and future research directions, was extracted and organized systematically.

To ensure accuracy and reliability, the extracted data were cross validated by comparing the findings across multiple articles. This process helped identify consistencies and discrepancies, enabling a more robust analysis and synthesis of the collected information.

The identified themes and patterns were further analysed and categorized to provide a comprehensive overview of the current state of automation and robotics technologies in container handling operations. The analysis aimed to uncover insights, highlight research gaps, and contribute to the overall understanding of the topic.

Throughout the data analysis process, careful documentation and note-taking were maintained to ensure transparency and reproducibility. The findings and insights derived from the analysis were then synthesized and presented in a coherent manner to meet the research objectives and questions.

3. RESULTS

3.1 Existing Approaches and Models for Optimizing Container Handling Operations in Automated Container Terminals

The integration of automation and robotics technologies in container handling operations offers the potential to improve efficiency, productivity, and safety. Automated systems like AGVs and yard cranes enhance the speed and accuracy of container transportation [3]. Robotics further diminish dependence on manual labour, reducing injury risks and bolstering operational consistency.

Table 1 provides an overview of existing approaches and models for optimization. These studies focus on various aspects such as task allocation, yard crane management, and integrated scheduling. Other areas of emphasis include robot coordination, AGV dispatching and routing, quay crane scheduling, control optimization, deadlock detection and recovery, and AGV speed optimization. Using mathematical models, simulation techniques, optimization algorithms, and heuristics, the authors tackle challenges to enhance the efficiency of container handling processes. Experimental evaluations demonstrate the effectiveness of these approaches in enhancing operational performance and balancing workload among equipment.

Table 1

Existing Approaches and Models for Optimizing Container Handling Operations in Automated Container Terminals

Reference	Study Overview
[3] Chen. et al. (2020)	This paper proposes a multi-robot task allocation framework for yard crane and AGV scheduling in automated container terminals. The framework aims to optimize the allocation of tasks among multiple

	robots to improve the overall efficiency of container handling operations. It considers various constraints and objectives, balancing the workload among the robots. The authors present a mathematical model and develop a solution approach based on mixed-integer linear programming and heuristic algorithms. They conduct experiments and comparative analyses to evaluate the effectiveness of the proposed framework.
[8] Legato et al. (2008)	This study focuses on yard crane management in automated container terminals. The authors use simulation and optimization techniques to improve the efficiency of yard crane operations. They develop a simulation model to analyse the performance of different yard crane management policies and identify areas for improvement. Based on the simulation results, they propose an optimization model to optimize yard crane assignment and scheduling. The model aims to minimize the total travel distance and handling time of yard cranes. The authors validate the effectiveness of their approach through numerical experiments.
[12] Naeem et al. (2023)	This comprehensive review paper discusses the integrated scheduling of quay cranes, automated guided vehicles (AGVs), and yard cranes in automated container terminals. It provides an overview of the existing literature on this topic, highlighting different approaches and models proposed in previous studies. The paper discusses various aspects of integrated scheduling, such as scheduling objectives, problem formulations, solution techniques, and performance evaluation. It also identifies research gaps and suggests directions for future research in this area.
[13] Stavrou et al. (2017)	This paper addresses the assignment and coordination of autonomous robots in container loading terminals. The authors propose a decentralized multi-agent system for robot assignment and coordination, considering various constraints and objectives. The system utilizes a negotiation mechanism among the robots to determine task assignments and coordinate their actions. The proposed approach aims to improve the efficiency and flexibility of container loading operations in automated terminals. The authors evaluate the performance of their system through simulations and highlight the benefits of the decentralized approach compared to centralized coordination.
[14] Sun et al. (2023)	This survey paper provides an overview of AGV-based vehicle transportation in automated container terminals. It discusses the challenges and opportunities of using AGVs for container transportation within terminals and reviews the existing literature on AGV-based transportation systems. The paper covers various aspects, including AGV deployment strategies, routing algorithms, coordination mechanisms, and performance evaluation. It also highlights emerging trends and future research directions in AGV-based transportation in automated container terminals.
[15] Wang & Zeng (2022)	This paper presents a branch-and-bound approach for AGV dispatching and routing problems in automated container terminals. The authors propose a mathematical model to optimize AGV dispatching and routing decisions, aiming to minimize the total travel distance and the duration of container transportation. They develop a branch-and-bound algorithm to solve the problem efficiently. The approach considers various constraints, such as time windows, AGV capacity, and precedence relations between tasks. The authors conduct numerical experiments to evaluate the performance of their approach and compare it with other methods.
[16] Wei et al. (2023)	This study focuses on quay crane scheduling with time window constraints in automated container ports. The authors propose a mathematical model to optimize the quay crane scheduling decisions, considering various constraints and objectives. They develop a solution approach based on mixed-integer linear programming to solve the problem. The proposed approach aims to minimize the total completion time of vessel operations and balance the workload among quay cranes. The authors validate the effectiveness of their approach through computational experiments.
[18] Wu et al. (2022)	This paper addresses the control optimization of automated guided vehicles (AGVs) in container terminals. The authors propose a control optimization framework based on Petri networks and dynamic path planning. The framework aims to optimize AGV routing decisions and improve the efficiency of container transportation. It considers various factors, such as AGV congestion, battery levels, and traffic conditions. The authors present a case study to demonstrate the effectiveness of their approach in reducing travel time and improving the overall performance of AGV operations.
[19] Wu et al. (2022)	This paper focuses on deadlock detection and recovery for interacting equipment in automated container terminals. The authors propose a Petri-net-based approach to detect and recover from deadlocks that

	may occur among the equipment, such as AGVs and yard cranes. The approach utilizes the state information of the equipment and applies Petri net theory to analyse the system's behaviour and detect deadlock situations. The authors develop a recovery strategy to resolve deadlocks and restore the system's operation. The proposed approach aims to enhance the reliability and availability of automated container terminal operations.
[21] Xing et al. (2023)	This paper addresses the integrated dispatching and scheduling of automated guided vehicles (AGVs) with speed optimization in container terminals. The authors propose an integrated optimization model that considers AGV dispatching, vehicle routing, and speed control decisions. The model aims to minimize the total completion time of container transportation and balance the workload among AGVs. The authors develop a solution approach based on mathematical programming and compare the performance of different algorithms. The proposed approach shows improvements in terms of operational efficiency and energy consumption compared to traditional methods.
[22] Yang et al. (2018)	This paper presents an integrated scheduling method for AGV routing in automated container terminals. The authors propose a mathematical model that considers multiple objectives, including minimizing travel distance, balancing the workload among AGVs, and avoiding conflicts among AGVs and other equipment. They develop a heuristic algorithm based on an iterative search process to solve the scheduling problem efficiently. The authors evaluate the performance of their approach through computational experiments and compare it with other methods.
[25] Zhuang et al. (2022)	This paper addresses the optimization of intelligent handling equipment scheduling at automated container terminals. The authors propose an optimization model that considers bidirectional flows, limited buffers, and equipment utilization. The model aims to optimize the scheduling of handling equipment, such as quay cranes and AGVs, to improve operational efficiency. The authors develop a solution approach based on mathematical programming and conduct numerical experiments to evaluate the effectiveness of their approach.

3.2 Impact of Integration of Automation and Robotics Technologies on Efficiency and Performance of Container Handling Processes

Efficient equipment scheduling is important for improving the overall productivity and performance of container terminals. Scheduling the utilization of equipment such as quay cranes, yard cranes, and AGVs plays a role in reducing waiting times, maximizing equipment utilization, and optimizing workflow.

Stowage planning focuses on optimizing the arrangement of containers within vessel bays to maximize capacity and minimize the number of shifts required during loading and unloading [2] [5] [6] [17]. Finding optimal solutions within a reasonable computational time frame is challenging due to the large-scale and combinatorial nature of the problem.

In Figure 1, several speed optimization techniques for loading and unloading operations are presented, illustrating the interdependence of each strategy. Notably, dispatching efficiency is influenced by optimized stowage and task allocation, and through iterative feedback, the overall container handling process is continually refined and enhanced:

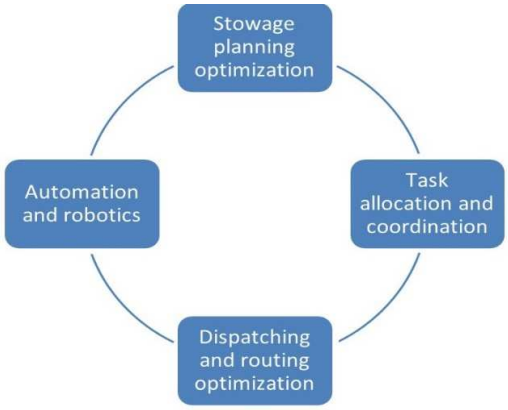

Fig.1. Speed optimization techniques proposed to enhance the performance of loading and unloading operations

- Stowage planning optimization: Mathematical models, such as mixed integer programming and heuristics, are employed to determine the optimal sequence and arrangement of containers in vessel bays, reducing the number of shifts required for loading and unloading [2], [6], [17].
- Task allocation and coordination: Multi-robot task allocation frameworks and integrated scheduling methods can be used

to assign tasks to equipment based on various factors, including proximity, availability, and operational requirements [3], [13], [22].

- Dispatching and routing optimization: Dispatching algorithms consider real-time conditions, such as equipment availability, traffic congestion, and container priorities, to assign tasks to AGVs efficiently [15]. Routing algorithms determine the optimal paths for AGVs to minimize travel time and avoid conflicts [21], [24].
- Automation and robotics: AGVs can autonomously transport containers between quay cranes, storage areas, and truck loading bays, eliminating manual handling and reducing operation time [13]. Robotic cranes can also enhance speed and accuracy in container handling operations [9].

References [2], [6], [9], [13], [15], [17], [21], [22], and [24] provide insights into various speed optimization techniques for loading and unloading operations in container terminals. These references discuss the application of mathematical models, coordination methods, optimization algorithms, and automation technologies to improve operational speed and efficiency.

Table 2 provides a comprehensive overview of the impact of integrating automation and robotics technologies on the efficiency and performance of container handling processes in automated container terminals. The referenced studies highlight various aspects and approaches that contribute to optimizing container handling operations.

The papers discussed in Table 2 emphasize the potential of automation and robotics technologies to enhance efficiency in container handling processes.

They explore different areas such as task allocation, scheduling optimization, coordination of autonomous robots, control optimization of AGVs, deadlock detection and recovery, energy-efficient handling, and dispatching with speed optimization.

Table 2

Impact of Integration of Automation and Robotics Technologies on Efficiency and Performance of Container Handling Processes

Reference	Study Overview
[3] Chen et al. (2020)	This paper presents a multi-robot task allocation framework for yard crane and AGV scheduling in automated container terminals. It discusses the integration of automation and robotics technologies and highlights their potential to enhance efficiency in container handling processes.
[7] Hong et al. (2023)	This study focuses on the integrated scheduling optimization for container handling using driverless electric trucks in an automated container terminal. It evaluates the performance improvements achieved through automation and robotics technologies, emphasizing enhanced efficiency in container handling operations.
[13] Stavrou et al. (2017)	The paper proposes a method for assigning and coordinating autonomous robots in container loading terminals. It explores the integration of automation and robotics technologies to optimize container handling processes, aiming to improve efficiency and reduce operational costs.
[18] Wu et al. (2022)	This research presents a control optimization approach for automated guided vehicles (AGVs) in container terminals using Petri networks and dynamic path planning. It discusses how automation and robotics technologies contribute to improving container handling efficiency through optimized AGV control.
[19] Wu et al. (2022)	The study focuses on the detection and recovery of deadlocks in the control of interacting equipment in automated container terminals using Petri nets. It discusses the integration of automation and robotics technologies to enhance operational efficiency and avoid disruptions in container handling.
[20] Xin et al. (2022)	This paper introduces a mixed-integer nonlinear programming formulation and a customized genetic algorithm for energy-efficient container handling. It assesses the impact of automation and robotics technologies on improving efficiency and reducing energy consumption in container handling processes.
[21] Xing et al. (2023)	The research proposes an integrated approach for dispatching automated guided vehicles (AGVs) and scheduling equipment with speed optimization. It evaluates the performance improvements resulting from the integration of automation and robotics technologies in container handling processes.

3.3 Key Challenges and Future Research Directions in Integration of Automation and Robotics Technologies in Container Handling Operations

Integrating automation and robotics also poses challenges. Advanced control algorithms and communication networks are necessary to ensure seamless coordination and synchronization of automated systems. Safety considerations and interactions between automated and human-operated systems require careful management.

References [3], [12], [13], [21], [22], and [24] provide insights into the role of AGVs in optimizing container handling operations. They discuss the benefits of AGVs, the integration of AGVs with other systems, and the various optimization techniques employed in AGV implementation.

References [3], [9], [12], [22], and [23] provide valuable insights into the use of robotics solutions, including AGVs, in container yard operations. They discuss the integration of AGVs with other equipment, optimization algorithms, and the benefits of automated container stacking and pre-marshalling.

Based on the findings and discussions presented in the research papers, recommendations for implementation can be derived. These recommendations include the adoption of optimization models and algorithms for stowage planning [1], [5], [6], [17], the development of multi-robot task allocation frameworks for yard crane and AGV scheduling [3], the utilization of simulation and optimization methods for yard crane management [8], and the integration of automation and robotics for equipment dispatching and routing [11], [21], [22], [24]. Implementing these recommendations requires collaboration between port terminal operators, researchers, and technology providers.

Future research directions may include exploring advanced technologies such as machine learning and artificial intelligence to optimize container handling operations. Integration with emerging technologies like blockchain and Internet of Things (IoT) can also be explored to enhance traceability, transparency, and security in container movements. Furthermore, considering environmental sustainability and energy efficiency in port terminal operations can be an important area of investigation.

Collaborative research efforts between academia, industry stakeholders, and technology providers are important to address the limitations and further advance the field. By addressing these research gaps, future studies can contribute to the development of more effective and efficient solutions for container handling operations in port terminals.

Table 3 provides insights into the key challenges and future research directions in the integration of automation and robotics technologies in container handling operations. The referenced studies highlight various challenges and propose potential research directions to address them effectively.

The papers discussed in Table 3 identify several common challenges in the integration of automation and robotics technologies in container handling processes. These challenges include coordination, communication, resource allocation, task allocation, optimization, equipment scheduling, AGV dispatching, routing and coordination, deadlock detection and recovery, conflict resolution, flow management, and buffer utilization.

Table 3

Key Challenges and Future Research Directions in Integration of Automation and Robotics Technologies in Container Handling Operations

Reference	Study Overview
[3] Chen et al. (2020)	This study presents a multi-robot task allocation framework for yard crane and AGV scheduling in automated container terminals. It identifies challenges related to coordination, communication, and resource allocation in the integration of automation and robotics technologies and suggests future research directions to address these challenges.
[11] Meiswinkel (2018)	The book discusses combinatorial optimization and mechanism design problems at container ports. It provides insights into the challenges of integrating automation and robotics technologies in container handling operations and suggests future research directions in the context of container ports.

[12] Naeem et al (2023)	This article provides a comprehensive review of the integrated scheduling of quay cranes, automated guided vehicles (AGVs), and yard cranes in automated container terminals. It highlights key challenges and proposes future research directions to optimize the integration of automation and robotics technologies in container handling processes.
[13] Stavrou et al. (2017)	The paper focuses on the assignment and coordination of autonomous robots in container loading terminals. It discusses challenges related to task allocation, coordination, and optimization in the integration of automation and robotics technologies. The study suggests future research directions to improve the efficiency and coordination of robot-assisted container handling processes.
[14] Sun et al (2023)	This survey paper explores AGV-based vehicle transportation in automated container terminals. It identifies challenges related to AGV dispatching, routing, and coordination and suggests future research directions to address these challenges in the integration of automation and robotics technologies in container handling operations.
[19] Wu et al. (2022)	The study focuses on deadlock detection and recovery for the control of interacting equipment in automated container terminals. It discusses challenges associated with equipment coordination and proposes future research directions to improve the reliability and efficiency of the integration of automation and robotics technologies in container handling processes.
[21] Xing et al. (2023)	This research proposes an integrated approach for dispatching AGVs and scheduling equipment with speed optimization in automated container terminals. It identifies challenges related to AGV dispatching, equipment scheduling, and optimization and suggests future research directions to enhance the integration of automation and robotics technologies in container handling operations.
[22] Yang et al. (2018)	The paper presents an integrated scheduling method for AGV routing in automated container terminals. It discusses challenges related to AGV routing, scheduling, and conflict resolution and proposes future research directions to improve the integration of automation and robotics technologies in container handling processes.
[24] Zhong et al. (2020)	This study focuses on multi-AGV scheduling for conflict-free path planning in automated container terminals. It addresses challenges related to AGV scheduling, path planning, and conflict resolution and suggests future research directions to optimize the integration of automation and robotics technologies in container handling operations.
[25] Zhuang et al. (2022)	The article discusses the optimization of integrated scheduling for handling equipment with bidirectional flows and limited buffers in automated container terminals. It identifies challenges related to equipment scheduling, flow management, and buffer utilization and proposes future research directions to enhance the integration of automation and robotics technologies in container handling processes.

4. CONCLUSIONS

The research papers reviewed in this study focused on various aspects of container handling operations in port terminals. The papers proposed optimization models, algorithms, and frameworks to improve the efficiency, productivity, and safety of port terminal operations. The studies aimed to address challenges such as resource utilization, congestion, and scheduling conflicts through the application of automation, robotics, and optimization techniques.

By implementing the findings and recommendations from these papers, port terminal operators can enhance their operational efficiency, improve resource utilization, reduce energy consumption, and enhance safety. The implications can guide decision-making processes and solutions for optimizing various aspects of port terminal operations.

These contributions advanced the understanding of container handling processes and provided practical solutions for enhancing operational efficiency and productivity.

While the reviewed papers provided insights, there are certain limitations and opportunities for future research. Some papers focused on specific aspects of port terminal operations, and there is a need for more comprehensive approaches that consider the integration of multiple processes. Additionally, real-world implementation and validation of the proposed models and algorithms are often limited, more empirical studies are needed to assess their practical feasibility and effectiveness.

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Automatizare și robotică pentru manipularea eficientă a containerelor în terminalul portuar: Recenzie

Această lucrare prezintă o recenzie privind optimizarea proceselor de manipulare a containerelor în porturile maritime prin integrarea vehiculelor cu ghidare automată, a soluțiilor robotizate în curtea terminalului de containere, inventariere automată în depozit, programarea echipamentelor cu optimizare a vitezei etc. Cercetarea se concentrează pe abordarea provocărilor asociate cu operațiunile eficiente de încărcare și descărcare la terminal. Studiul explorează utilizarea macaralelor automate, a sistemelor robotizate, precum și algoritmii de control inteligenți pentru a îmbunătăți productivitatea și siguranța operării. Descoperirile evidențiază progresul automatizării și al roboticii în logistica portuară, oferind informații valoroase pentru îmbunătățirea eficienței operaționale, maximizarea utilizării resurselor și minimizarea consumului de energie.

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