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Optimizing integrated seaside operations at port terminals: A systematic review using the spider framework and future research directions

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Abstract
This paper presents a systematic review of integrated seaside operations problems using the SPIDER framework and the PRISMA flow diagram. The review aims to synthesize existing research, identifying current methodologies, key findings, and gaps in the literature to guide future research and practice. By focusing on the integration of berth allocation, quay crane assignment, and quay crane scheduling, this review provides a comprehensive understanding of the challenges and solutions in optimizing port terminal operations. The insights gained will aid in developing more effective and efficient strategies for managing the complex interactions within seaside planning.

Keywords: Berth allocation, quay crane assignment, quay crane scheduling, optimization, port terminal management

Introduction

Maritime transportation is the backbone of global trade, managing over 80% of international trade by volume [1]. Port terminals serve as critical hubs in this supply chain, ensuring efficient transfers between land and maritime transportation. However, challenges such as congestion, infrastructure limitations, and the increasing size of vessels hinder their efficiency and productivity. These issues necessitate meticulous planning and optimization of key processes like berth allocation, quay crane assignment, and quay crane scheduling.

The Berth Allocation Problem (BAP) involves assigning arriving vessels to specific berthing positions, aiming to minimize service time. The Quay Crane Assignment Problem (QCAP) focuses on the efficient distribution of quay cranes to berthed vessels, optimizing crane productivity and reducing operational costs. The Quay Crane Scheduling Problem (QCSP) schedules the operations of assigned quay cranes to minimize the makespan, enhancing overall port productivity [2]. This investigation aims to delve into these crucial stages of port terminal operations-BAP, QCAP, and QCSP-to identify and propose solutions that can significantly enhance the efficiency and productivity of port terminals, ensuring their competitiveness in the global maritime industry.

A systematic literature review

The aim of a systematic review is to comprehensively gather and critically analyze all relevant research on a specifically formulated question, with the goal of synthesizing the findings to offer evidence-based answers or insights. This process involves discussing a detailed and structured methodology in the following section. It also aims to minimize bias through the exhaustive identification of relevant studies, careful selection and appraisal of studies, and the systematic synthesis of findings. This approach provides a reliable and comprehensive overview of the evidence related to a specific question or topic, which can inform policy, practice, and further research. Our principal research review questions is:

How can advanced optimization techniques and integration methods be effectively applied to optimize the combined berth allocation, quay crane assignment, and quay crane scheduling in different terminals type, considering diverse performance metrics ?

The steps of conducting a systematic review are methodical and detailed, aimed at minimizing bias and ensuring a comprehensive evaluation of the available evidence on a specific research question. While variations may exist across different guides or disciplines, the core process remains consistent (Figure 1).

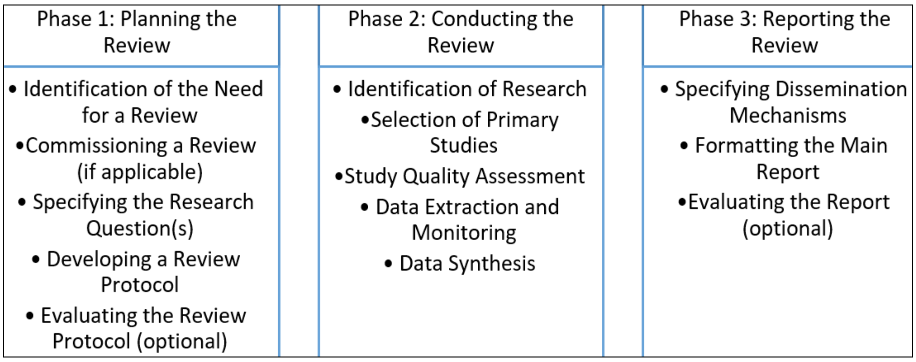

Fig 1: Steps of systematic review [3]

Planning the review

The main goal of the planning phase in a systematic review is to establish a clear and comprehensive plan that ensures a systematic and unbiased approach to gathering and analyzing relevant research evidence on a specific question or topic. This phase involves defining precise research questions using frameworks like SPIDER to ensure focus and relevance. A detailed review protocol is then developed, specifying the methodology, study selection criteria, search strategies, data extraction methods, and synthesis plans. Additionally, a comprehensive literature search strategy is designed to identify pertinent databases and sources, ensuring thorough and relevant data collection.

[4] introduced the SPIDER framework. The authors proposed the SPIDER tool as an alternative to the PICO (Population, Intervention, Comparison, Outcome) framework for defining key components of review questions and standardizing search methods in qualitative evidence synthesis. Their aim was to address the limitations of the PICO framework in capturing the nuanced aspects of qualitative research, such as unobservable outcomes and subjective constructs. The SPIDER framework surpasses PICO in qualitative research due to its tailored design for qualitative inquiries, encompassing components like Sample, Phenomenon of Interest, Design, Evaluation, and Research type. This specificity ensures better alignment with the nuanced aspects of qualitative studies, facilitating more comprehensive representation and flexibility in search strategies.

Search Engines, Databases, and Search Terms

To identify studies addressing the research question a comprehensive search will be conducted across relevant academic databases:

- ScienceDirect (https://www.sciencedirect.com/),
- Google Scholar (https://scholar.google.com/)
- And Springer (https://www.springer.com/gp)

Table 1: Spider Framework

	Terms	Questions
S	Sample	What is the target population or sample under study? Who or what are the subjects or participants in the research?
PI	Phenomenon of Interest	What is the main concept or phenomenon being investigated in the research? What specific aspect of the phenomenon is of interest?
D	Design	What type of study design or methodology was employed in the research? How was the research conducted, including data collection methods and procedures?
E	Evaluation	What outcomes or evaluation criteria were used to assess the results of the research? How were the findings measured or evaluated?
R	Research Type	What type of research methodology was employed in the study (qualitative, quantitative, etc) ? What approach or methodology guided the research process?

Google Scholar's broad search capabilities allowed exploration of a wide range of research on integrated seaside planning in port terminals, while ScienceDirect's focus on peer-reviewed journals provided in-depth analysis in relevant fields like transportation and logistics. Springer offers a wide range of scholarly literature across various disciplines, further enriching our investigation. This combination of databases offered a strong foundation for our investigation, aligning well with the scope and focus of this review.

A combination of keywords and controlled vocabulary terms will be used to refine the search and ensure relevant studies are captured. These terms include: "integrated planning," "problems," "berth allocation," "quay crane assignment," "quay crane scheduling," "port terminals," "container terminals," "bulk," and "multipurpose terminal".

Table 2: Search Terms

Component	Key Term	Alternate Terms	Explanation
Sample (S)	Port Terminal	Container Terminal, Bulk Terminal, Multipurpose Terminal	Variants of terminal types to capture diverse literature
Phenomenon of Interest (PI)	Integrated Planning Problems	Integrated Berth Allocation, Quay Crane Assignment, Quay Crane Scheduling	Key aspects of integrated seaside planning under study
Design (D)	Methods	Techniques, Approaches	Methodological approaches considered in research
Evaluation (E)	Service Time	Turnaround Time, Operational Efficiency	Specific aspect of performance being evaluated
Research Type (R)	Qualitative Studies	Empirical Studies, Statistical Analysis	Nature of the research approach utilized

Research Query

The search query using Boolean operators would be: ("integrated planning problems" OR "integrated berth allocation" AND "quay crane assignment" AND "quay crane scheduling") AND ("port terminals" OR "container terminals" OR "bulk port" OR "multipurpose port") AND ("methods" OR "techniques" OR "approaches")

Conducting the review

After applying our research query, we initially identified 1290 publications. The next critical step involves categorizing these selected research works based on specific inclusion and exclusion criteria.

Selection Criteria

Table 3: Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Published from 2015 until 2023	Papers that do not addressintegrated seaside optimization problems
Written in English	Studies that do not align with our search objectives
Clearly address the integration of berth allocation, quay crane assignment, and scheduling in port terminals.	Keywords that are not relevant to the topic
Types (Only those impacted or indexed in journals and conferences)	Unclear user instructions

Screnning Process

The literature review screening process involves two main stages: initial screening of titles and abstracts, followed by full-text review. This structured approach ensures that only the most relevant studies are included. During Stage 1, titled "Title and Abstract Screening," the aim is to quickly assess the relevance of the 1290 identified publications based on predefined inclusion and exclusion criteria (Outlined in Table 3). This involves carefully reading the titles and abstracts of each publication and evaluating them against the criteria. Publications meeting all inclusion criteria and not falling under any exclusion criteria are marked for full-text review, while those that do not meet the criteria are excluded. This stage aims to significantly reduce the number of publications, focusing on those likely to provide pertinent information, thus preparing for a manageable full-text review stage.

Stage 2, the Full-Text Review, aims to comprehensively assess the remaining studies to determine their relevance and eligibility through a detailed examination of their full texts. This phase involves obtaining and thoroughly reading the full texts of the publications that passed the initial screening. Each study is evaluated to confirm that it meets all predefined inclusion criteria and does not fall under any exclusion criteria. Decision-making involves including publications that fulfill all criteria and contribute relevant insights to the research question, while excluding those that do not meet the criteria upon detailed review. This stage finalizes the selection of studies to be included in the literature review, ensuring that only the most relevant and high-quality studies are chosen for a comprehensive and focused analysis.

The PRISMA flow diagram (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) illustrates the systematic process of study selection in this review. It begins with identifying potential studies through comprehensive searches across electronic databases and other sources, yielding 1573 studies in total. Initial screening involved removing 364 duplicate records and excluding 292 studies that did not meet preliminary inclusion criteria, leaving 917 studies for title and abstract screening. After assessing relevance, 490 studies were excluded based on their titles and abstracts, resulting in 427 studies for full-text retrieval. During the eligibility phase, attempts were made to retrieve the full text for 427 studies, but only 142 were successfully retrieved. From these, 62 studies were excluded following a thorough full-text review, with reasons including 26 papers not addressing integrated seaside optimization problems and 36 studies deemed irrelevant after abstract analysis. In the final inclusion phase, a detailed review of the remaining 80 studies led to the exclusion of 35 studies for various reasons. Ultimately, 45 studies were included in the review and considered for meta-analysis, as depicted in the PRISMA flowdiagram in Figure *2*. Each included publication was assessed for study quality and level of evidence, following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) as outlined by [5].

Quality Assessment Using CASP Checklists

Quality assessment is a critical step in a systematic review to ensure the reliability and validity of the included studies. This process evaluates the methodological quality of the studies and their risk of bias. The Critical Appraisal Skills Programme (CASP) checklists are effective tools for evaluating the methodological rigor and potential bias in studies. These checklists cover various aspects of study quality and are adaptable to different types of research design.

Using CASP checklists ensures that only high-quality evidence is included in the review, providing reliable findings. Below is an overview of how to use CASP checklists for quality assessment in the context of integrated seaside planning problems in port terminals.

Key Aspects of Quality Assessment

- **Type of Ports:** Determine if the study clearly defines the type of port terminal (e.g., container terminal, bulk terminal, multipurpose terminal). Then we assess the relevance of the port type to the research question.
- **Optimization Methods:** Evaluate the methods used for berth allocation, quay crane assignment, and scheduling. This ensures the methods are appropriate and clearly described.
- **Integrated Planning Approach:** Check if the study addresses integrating different planning problems (e.g. Deep, and Functional). It assess the comprehensiveness and feasibility of the integrated approach.

Performance Metrics: Identify the performance metrics used (e.g. service time, handling time, makespan, operational efficiency). This evaluate the appropriateness and clarity of these metrics in assessing the effectiveness of the optimization methods.

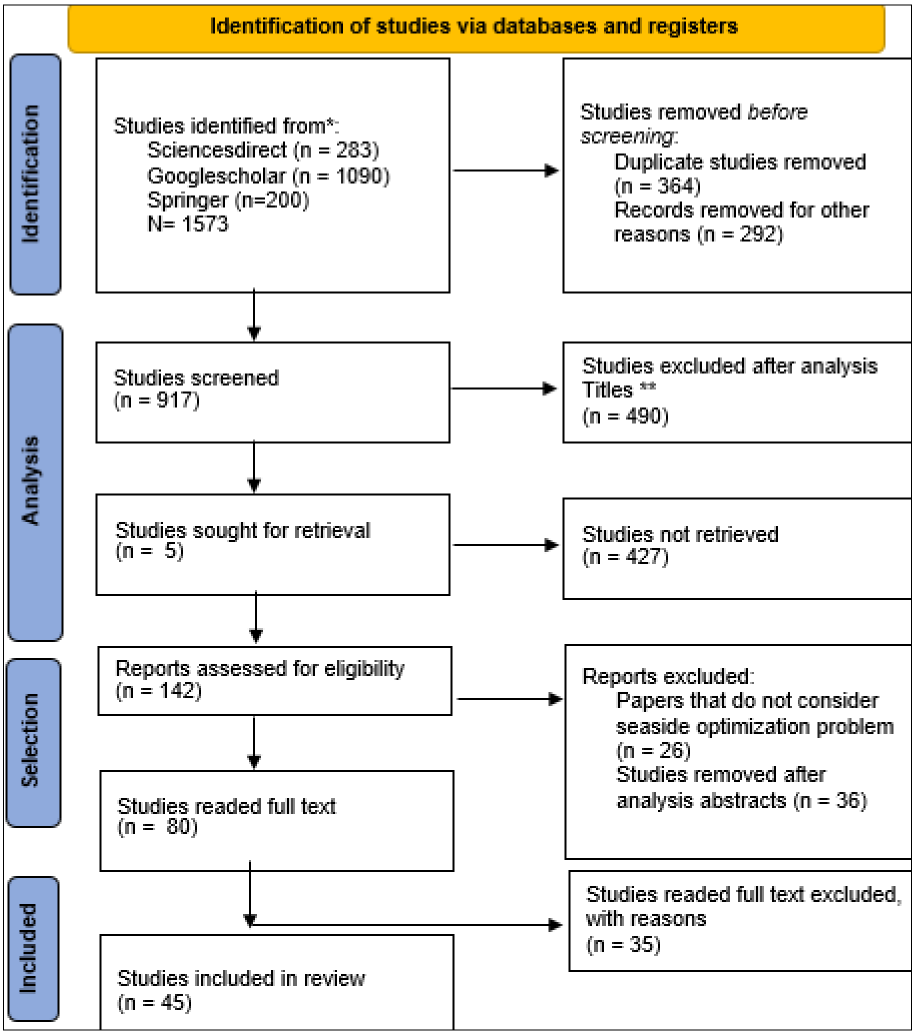

Fig 2: Prisma Flow Diagram

Reporting the review

Reporting on the review involves summarizing findings and assessments across different aspects (Table 4). Firstly, the study's classification of port terminals, such as container or bulk terminals, is evaluated for its alignment with the research focus. Secondly, methods for optimizing berth allocation, quay crane assignment, and scheduling are scrutinized for clarity and suitability. Thirdly, the integration of planning problems is analyzed for comprehensiveness and feasibility. Finally, the effectiveness of optimization methods is assessed using performance metrics such as service time, handling time, makespan, and operational efficiency, ensuring these metrics are appropriate and well-defined for evaluating method efficacy.

Distribution of Research Focus across Port Types

Figure 3 illustrates the distribution of different types of ports based on the classifycation in reviewed papers. Container terminals prominently dominate the chart, comprising 82% of the total distribution, underscoring their predominant role in contemporary port operations aligned with global trade dynamics. Bulk terminals, accounting for 7%, represent a significant but smaller segment, while multipurpose terminals follow with 2%. The category of ports handling both bulk and containers constitutes 5%. Notably, 4% of the data pertains to ports that were not classified in the reviewed papers. This distribution underscores a clear emphasis on container terminals within the literature, reflecting their critical importance in the modern maritime industry, although other terminal types also contribute to the overall landscape of port operations.

The findings suggest a clear research focus on container terminals, likely due to their economic significance and widespread adoption in global supply chains. The smaller representation of bulk and multipurpose terminals may indicate a potential area for further research into optimizing operations and efficiency in these sectors. The presence of unclassified ports highlights a need for standardized reporting and classification practices within port management literature to facilitate clearer comparative analyses and insights into global port operations.

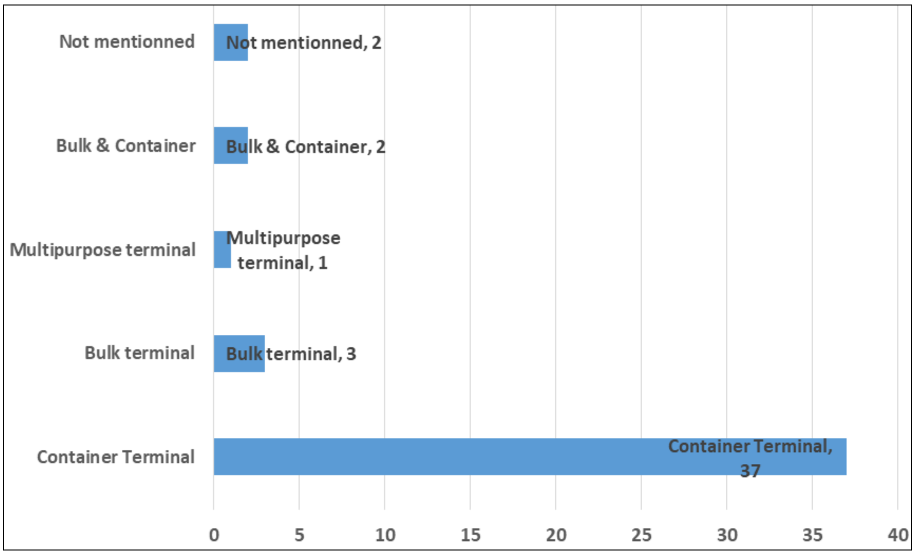

Fig 3: Distribution of Research Focus Across Port Types

Research Focus across Study Types

The distribution of study types and their characteristics are analyzed as follows:

- **Numerical Empirical Studies:** Represent the largest portion of the meta-analysis, comprising the majority of the papers. These studies typically use existing instances from the literature, such as those defined by [6], to maintain consistency and comparability across studies. Some studies also generate new instances to explore specific aspects of quayside planning not covered by existing instances, offering novel insights and addressing unique scenarios.
- **Case Studies:** Constitute a moderate portion of the meta-analysis. These studies utilize real instances from specific port terminals to examine the implementation and outcomes of quayside planning solutions in practical settings. By analyzing real-world cases, they provide detailed practical insights and validate theoretical models against actual operational data.
- **Review Literature:** Represent the smallest portion, with only three papers included in the meta-analysis. These reviews synthesize existing research on integrated quayside planning, categorizing and evaluating optimization methods used across different studies. They also identify gaps in the literature, suggesting areas where further research or new methods might be necessary to advance the field.

The systematic analysis using the SPIDER framework reveals a predominance of Numerical Empirical Studies and Case Studies in the meta-analysis on integrated seaside planning. These study types contribute significantly to understanding practical implementations and theoretical advancements in the field. Review Literature, while fewer in number, offers critical insights into the synthesis and evaluation of existing knowledge, highlighting areas for future research and methodological development.

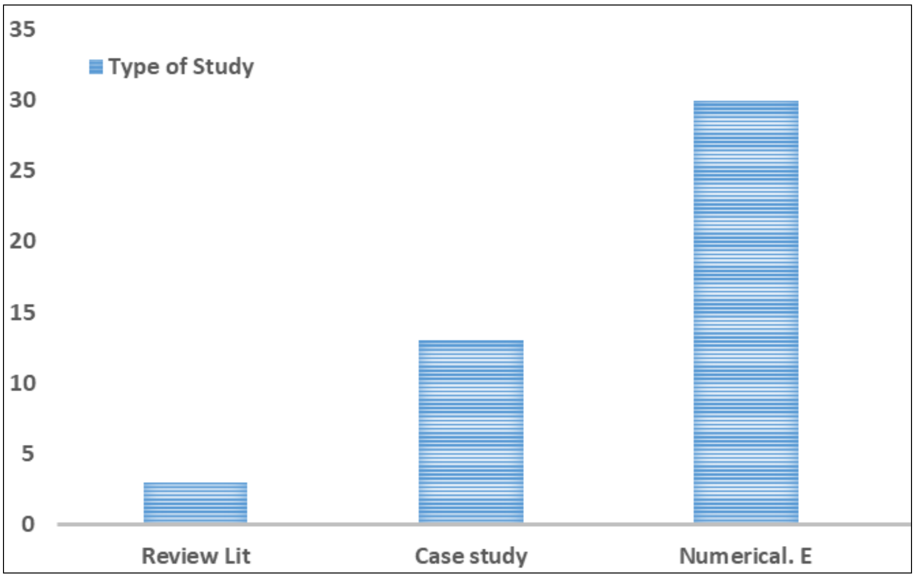

Fig 4: Research Focus Across Study Types

Focus on objective functions in integrated seaside planning

The studies reviewed encompass a range of methodologies, including those that minimize costs (e.g., overall cost reduction, cost of port stay times), minimize time (e.g., service time, turnaround time, handling time, makespan,

etc.), and promote sustainability (e.g., reducing carbon emissions, energy costs, and greenhouse gas emissions).
The distribution and characteristics of objective functions are analyzed as follows:

- Minimizing Costs: A significant focus in integrated seaside planning problems, with studies such as [7] and [8] targeting overall cost reduction, including factors like speed-up, delay, and penalty costs associated with port operations.
- Minimizing Time: Another prevalent objective function, with studies like [9] and [10] focusing on reducing total service time and turnaround time for vessels, respectively, to enhance operational efficiency and reduce waiting times.
- Other Objectives: Additional objectives include reducing handling time and minimizing delays and deviations. Studies by [11, 12, 13], and [14] address these aspects by minimizing handling, waiting, and delay times, and reducing costs associated with delays and improving departure times.
- Sustainability Objectives: In recent years, there has been a notable shift towards sustainability objectives in seaside planning. Studies like [15] and [16] highlight efforts to minimize carbon emissions, energy costs, and greenhouse gas emissions, reflecting a growing emphasis on sustainable practices in the maritime industry.

Using the SPIDER framework, the analysis reveals a diverse range of objective functions within integrated seaside planning problems. The predominant objectives focus on minimizing costs and time, reflecting traditional efficiency goals in port operations. However, there is an emerging trend towards sustainability objectives, reflecting broader industry shifts towards environmental responsibility and energy efficiency.

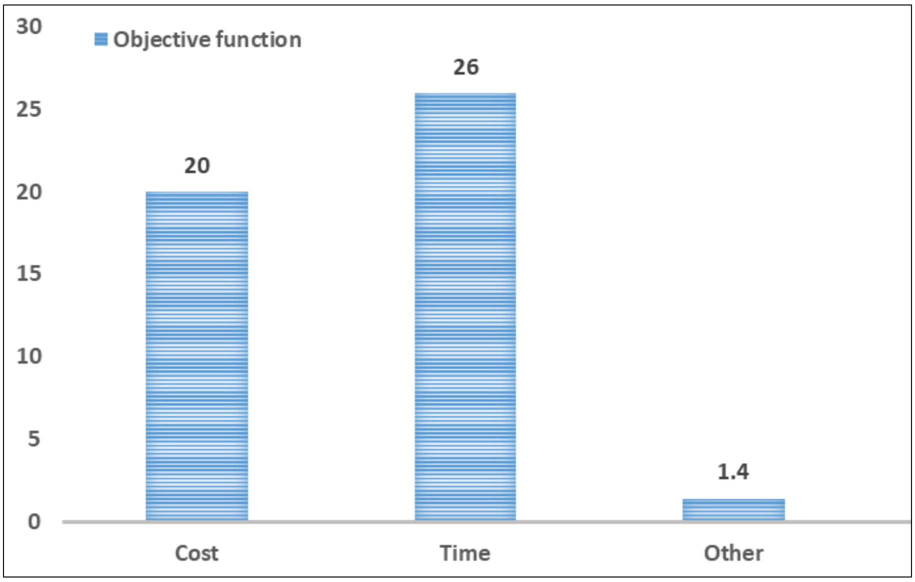

Fig 5: Classification by objective Function

Optimization methods across integrated seaside planning

The studies reviewed encompass a range of methodologies, including exact methods, Heuristics, and Metaheuristics, used to optimize complex problems in port operations.
The distribution and characteristics of optimization methods are analyzed as follows:

- **Exact Methods:** Prevalent in 18 studies, these methods guarantee optimal solutions but are computationally intensive, making them suitable primarily for smaller problems where computational resources are less constrained.
- **Heuristics:** Utilized in 10 papers, heuristics offer faster and more scalable solutions compared to Exact methods but do not guarantee optimality. They are suitable for larger and more complex problems where computational efficiency is prioritized over achieving the absolute optimal solution.
- **Metaheuristics:** Dominating with 14 papers, metaheuristics strike a balance between solution quality and computational efficiency. They are the preferred choice for addressing complex problems in integrated seaside planning due to their ability to explore large solution spaces effectively.
- Within Metaheuristics, methods such as Genetic Algorithms (GA), Simulated Annealing (SA), and Particle Swarm Optimization (PSO) are highlighted. These methods are adaptable to various integrated seaside planning problems, reflecting the need for flexible and robust optimization strategies in port operations.

Using the SPIDER framework, the analysis reveals a diversified use of optimization methods in integrated seaside planning. While exact methods ensure optimality, they are limited by computational intensity. Heuristics offer scalability but sacrifice optimality. Metaheuristics, particularly GA, SA, and PSO, emerge as versatile solutions balancing solution quality with computational efficiency, making them well-suited for complex port operation problems.

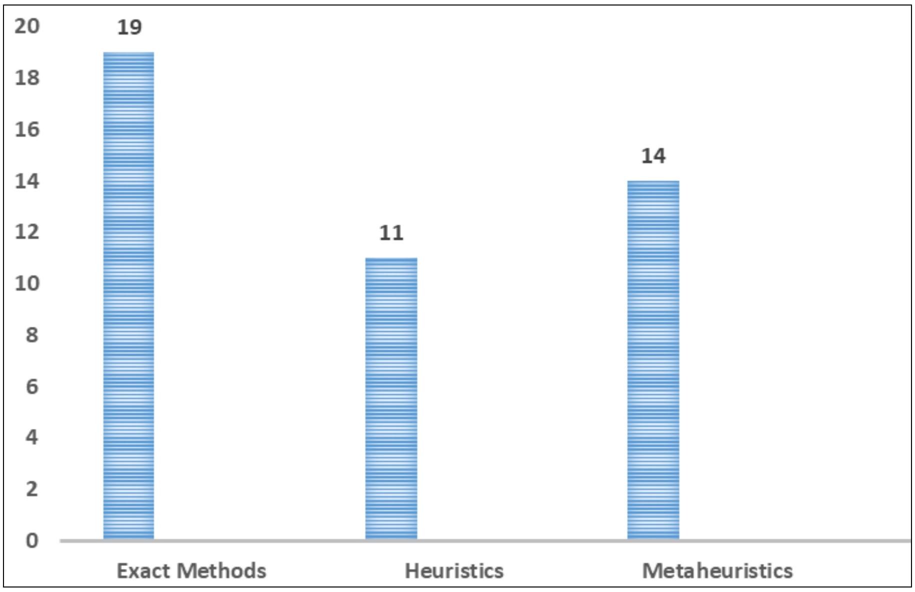

Fig 6: Optimization Methods Across Integrated Seaside Planning

Classification by type of integration

The studies reviewed encompass various methodologies, including those that employ Deep Integration (Simultaneous optimization of berth allocation and quay crane assignment) and Functional Integration (Sequential or separate optimization of these tasks).

The distribution and characteristics of integration approaches are analyzed as follows:

Deep Integration: Represented in 21 papers, this approach involves formulating unified models or approaches that concurrently optimize berth allocation and quay crane assignment. These studies typically employ techniques such as mixed-integer programming (MIP), genetic algorithms (GA), or other metaheuristic approaches to achieve optimal solutions by integrating these components as interdependent parts of a single optimization problem. Examples include studies by [7, 8, 9, 17], and [18], etc.

Functional Integration: Also represented in 21 papers, this approach involves addressing berth allocation, quay crane assignment, and scheduling as separate or sequential tasks. These papers typically optimize one component while treating the others as independent or loosely coupled tasks. They often use distinct models or heuristics for each task without explicit joint optimization. Examples include [19, 20, 21], and [22], etc.

Using the SPIDER framework, the analysis reveals a balanced distribution between Deep Integration and Functional Integration approaches within integrated seaside planning research. Deep Integration emphasizes holistic optimization to capture synergies and dependencies between berth allocation and quay crane assignment, potentially leading to higher efficiency and reduced computational complexity. In contrast, Functional Integration employs sequential or separate optimization strategies, focusing on individual tasks with limited coordination.

Table 4: A systematic review of 45 selected papers used PRISMA

Papers	Type of port			Type of study		Optimization techniques				Integration problems			Objective function			Type of integration	
	C	B	M	R	CS	ES	E	H	MH	BACAP	BACSP	BACASP	C	T	O	DI	FI
[7]	✓					✓	✓			✓			✓			✓	
[23]	✓			✓			-	-	-	✓	✓			✓		-	-
[11]	✓					✓			✓	✓			✓				✓
[19]	✓					✓		✓		✓				✓			✓
[9]	✓					✓				✓				✓		✓	
[20]	✓					✓	✓							✓			✓
[12]	✓					✓		✓	✓					✓		✓	
[21]	✓					✓			✓				✓				✓
[8]	✓												✓			✓	
[24]	✓					✓	✓							✓		✓	
[13]	✓					✓	✓					✓	✓			✓	
[25]	✓					✓		✓		✓			✓				✓
[17]		✓				✓	✓	✓				✓		✓		✓	
[26]	✓					✓		✓		✓			✓				✓
[27]	✓				✓	✓	✓			✓			✓				✓
[10]	✓					✓	✓		✓	✓					✓		✓
[28]	✓					✓	✓			✓			✓			✓	
[29]	✓				✓				✓		✓			✓			✓
[22]		✓			✓			✓		✓			✓				✓

[30]	✓					✓	✓			✓				✓		✓	
[31]	✓					✓	✓			✓				✓			✓
[32]	✓					✓			✓	✓			✓			✓	
[33]		✓			✓		✓	✓		✓			✓				✓
[34]	✓				✓		✓					✓		✓		✓	
[35]	✓				✓	✓		✓		✓			✓	✓			✓
[36]	✓					✓		✓				✓		✓		✓	
[37]	✓					✓	✓			✓			✓				✓
[38]	✓				✓		✓			✓				✓		✓	
[39]	✓					✓	✓			✓			✓				✓
[40]	-	-	-		✓		✓	✓				✓		✓		✓	
[41]	✓				✓		✓			✓				✓		✓	
[18]	✓					✓	✓		✓		✓				✓		✓
[42]	✓	✓				✓	✓	✓	✓	✓							✓
[43]	✓			✓			-	-	-	✓	✓			✓		-	-
[44]	✓					✓			✓	✓				✓			✓
[45]	✓					✓			✓	✓				✓		✓	
[46]			✓		✓		✓			✓				✓	✓		✓
[47]	✓			✓	-	-	-	-	-	✓	✓	✓				-	-
[48]	✓					✓		✓	✓			✓		✓			✓
[16]	✓				✓		✓		✓	✓			✓	✓	✓	✓	
[49]	✓					✓	✓	✓		✓				✓		✓	
[50]	✓				✓				✓	✓			✓			✓	
[15]	✓				✓	✓	✓					✓	✓	✓		✓	
[51]	✓					✓			✓		✓			✓			✓
[52]	✓					✓			✓	✓			✓			✓	

Type of port (C= Container, B= Bulk, M= Multi-purpose); Type of Study (R= Review study, C=Case study, ES= Empirical Study); Optimization techniques (E= Exact, H= heuristic, MH= Metaheuristic); Integration problems (BACAP= berth allocation and quay crane assignment problems, BACSP= berth allocation and quay crane scheduling problems, BACASP= berth allocation, quay crane assignment, and problems quay crane scheduling problems); objective function (C= Cost, T= Time, O= Others objectives); Type of Integration (DI= Deep Integration, FI= Functional Integration)

Conclusion

Our review on the integrated planning in port terminals has provided valuable insights. The predominant research focus on container terminals highlights their critical role in contemporary port operations, yet it also reveals a significant gap in research dedicated to bulk and multipurpose terminals. This gap presents an opportunity for researchers to contribute by concentrating on multipurpose ports, which play a versatile role in handling diverse types of cargo. In alignment with current trends in the literature, approaches like genetic algorithms (GA) are favored in existing research due to their effectiveness in addressing the complexity of integrated planning problems. Furthermore, deep integration and sequantiel integration are both proved their pêrformance on the integratation of the seaside planning problems. Future research could explore hybrid approaches or advanced integration strategies to further enhance operational efficiencies and decision-making in maritime logistics. By integrating advanced optimization techniques with effective planning and operational strategies, terminal operators can optimize berth allocation, quay crane assignment, and scheduling across different terminal types while achieving diverse performance metrics efficiently. This approach not only enhances operational efficiency and cost-effectiveness but also supports sustainable growth and competitiveness in maritime logistics.

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