



Production schedule optimization for FRP products in Boat Manufacturing using Meta- heuristic Optimization Algorithms: A Literature Study

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Abstract

The highly competitive field of Fiber-Reinforced Polymer (FRP) boat manufacturing relies heavily on efficient production scheduling for increased productivity and lowered production costs. This study deals with the use of meta-heuristic optimization algorithm (especially Genetic Algorithm (GA)) in optimizing production scheduling as well as resource allocation and bottleneck and contingency management, meeting deadlines set for the said processes. On the other hand, classical scheduling theory will not be effective for boat production (displaying nautical characteristics) due to different parameters. Meta-Heuristic optimization algorithms are another approach in which optimal schedules are obtained by allowing optimal schedules to evolve over time. Here, work has been advanced because a model based on Meta- heuristic Optimization Algorithms is developed for FRP boat manufacturing processes. Some of the important factors like work-task ordering and availability of resources are represented as chromosomes and their corresponding fitness functions are defined to reduce the production time and enhance the use of available resources. The results obtained from the simulation confirmed that this strategy is useful in decreasing lead times and increasing production performance. Implementing genetic algorithms, this research helps to realize more practical and efficient means of scheduling in FRP boat production that is rapid and flexible. The outputs from this research will also help in building more efficient and responsive production systems which are in line with the current trends and future pressures in the industry.

Keywords: Boat Manufacturing; Fiber-Reinforced Polymer (FRP); Production scheduling; Meta- heuristic optimization; Research Gaps

1. Introduction

Optimizing the production schedule seeks to increase productive capacity, output, and ultimately profit. Properly sequencing the orders and timing of completion of the production activities allows manufacturers to achieve smooth work processes, reduce idle time, and efficiently utilize labor, materials, and equipment resources. In this optimization, the goal is to find the most optimal time schedule for the production targets, along with meeting the customers demand on time, minimizing the production cost, or, in other words, optimizing the overall

throughput [1]. Genetic algorithms (GAs) are engines of optimization and searching based on the principles of natural selection and genetics in biological systems [2]. Fiber Reinforced Polymer (FRP) products are now a fundamental part of today's boat construction because of their combination of strength, longevity, and adaptability [3]. FRP is a composite, which is formed by the reinforcement of polymers with fibers (glass, carbon, and aramid) and improves the structural stability of it [4]. Originally known as an aerospace and automotive material, FRP now has a growing popularity in marine applications due to manufacturers' interest in lightweight construction and excellent environmental performance.

FRP provides superior ship design, performance and life time characteristics for boat building that FRP will remain a competitive alternative to traditional materials such as wood or metal. The important property of FRP with respect to boat manufacturing is Strength: weight ratio more than conventional materials [5]. FRP boat structures are lighter and thus provide better fuel economy as well as handling characteristics all while maintaining structural integrity. It is especially beneficial for fast and performance vessels where weight is the priority. Meanwhile, due to the lightweight properties of FRP, it accelerates transportation and assembly procedures, and repairs are easier hence reduce costs in terms of transport, assembly, and repair which ultimately also have cost implications on both manufacturers and owners. Durability is one of the major advantages that FRP presents to marine applications like boats subjected to continuous moisture, UV radiation, salt water, and temperature variation. Substantially inert to these changing environmental conditions as opposed to wood, which suffers decay, or metals, which corrode, FRP offers this substance a new being of strength application [6]. The very nature of strength gives boats a stature for shapes and functions to last for so long, even in so severe marine environments. Therefore, FRPs are often easy to maintain, and reparative costs are very low, which can be very helpful for the either recreational or commercial boat owner [7]. Besides durability and lightness, FRP provides an extremely design flexibility, which opens up the possibilities for boat manufacturers to implement new shapes and structures.

FRPs can be shaped into intricate geometries, allowing designers to shape hulls and other components to maximize hydrodynamics and stability. This versatility is especially valuable in custom or luxury boats where the look and design are very important [8]. Using FRP, manufacturers can balance function and aesthetics to cater to a broad range of desires in the boating market. But environmental advantages of FRP contribute to its popularity in the marine sector, too. Composites made of reinforced plastic (FRP) can integrate pre-consumer or post-consumer waste into the composite, and their service life is longer than that of conventional materials, which leads to a reduced need for replacement [9]. In addition, even though FRP cannot be completely degraded, research on recycling and sustainable manufacturing practices is still in progress, and it is encouraging as far as FRP's future is concerned. This is one reason why FRP is an environmentally sustainable option in a market that is rapidly growing to emphasize sustainability. The use of FRP products in boat building played a transformative role in the industry by bringing to market a material that offered the properties of performance, strength, and design freedom [10]. Usage is wide, from personal crafts to commercial vessels, on account of its resilience in the marine domain along with the scope of creativity in design. Future advances in materials and technology will assure that FRP remains a bulwark of the boat-building business and have a potent impact on marine engineering.

The main objective of this study is to explore the application of genetic algorithms (GAs) for optimizing production schedules in Fiber-Reinforced Polymer (FRP) boat manufacturing.

The major contribution of this literature review is:

- A literature review is undergone with 60 research articles collected in the period of 2018-2024.
- Focusing on keywords such as boat manufacturing, fiber-reinforced polymer (FRP), production scheduling, and meta-heuristic optimization.
- This research analyzes the techniques likely A* Algorithm, Genetic Algorithm (GA), Hybrid Optimization (LP & GA), Matheuristics (GA & MILP), and GA-ANN for FRP manufacturing.
- The research gaps of the study are identified by undergoing this review.

The remaining sections of this paper are structured as follows: The review of literature is presented in Section 2, followed by the identification of research gaps in Section 3, and the conclusion in Section 4.

2. Review of Literature

2.1 Optimizing Boat Production Schedules with Meta-Heuristic Optimization

2.1.1 Review

Genetic algorithms (GAs) have been proposed for the optimization of boat production schedules and investigated within by maritime operations, scheduling, and logistics to name a few. These analyses depict the potential of GAs in improving operational efficiency for a wide spectrum of maritime activities such as berthing scheduling, ship routing and logistics management. As of 2018, Dulebenets et al. proposed an evolutionary algorithm with self-adaptive dynamic solutions for berth chartering optimization whose primary aim was to minimize downtime and tardiness of the vessels. This combined the linear mixed integer programming with self-adaptive evolutionary algorithms, which succeeded in improving objective function values without drastically morphing computational time. Likewise, Azevedo et al. applied a genetic algorithm to the problem of 3D Stowage Planning (3D SP) and/or Scheduler of Quay Cranes (SQC) in 2018. Their model accounted for a 45.82% increase in contending load/unload times that could otherwise avoid users from incurring charges through optimized port operations. In 2020, Dong and Bian suggested automated SPRD methods employing an A* algorithm and a genetic algorithm, respectively. The method provided changes in routing quality and variety, which experiments successfully asserted as an effective algorithm.

Furthermore, Pereire et al. had a hybrid of linear programming and grammar-based genetic programming used in 2020 in the scheduling of crude oil refineries, having their advantages such as winning the problems in multiple cases from real refineries. In 2021, Yin et al. developed an iterative variable grouping genetic algorithm (IVGGA) for vessel distribution optimization in berth scheduling. This approach performed well with moderate subgroup sizes and outperformed traditional genetic algorithms as the problem scale increased. Zhang and Qiao's 2023 decision support system (DSS) for speed optimization also employed a genetic algorithm to reduce fuel consumption by optimizing ship speed based on weather conditions and specific fuel oil consumption rates. In 2024, Li et al. reported a self-learning hyper-heuristic optimization algorithm for the logistics scheduling of

prefabricated modular cabin units on cruise ships, called GA-SLHH. It was found that this algorithm was able to shorten the path length by as much as 37%. Wen et al. (2024) extended the multi-objective optimization model with respect to ship scheduling, which incorporates the influences of port congestion and the environmental conditions. Their model, trained using a grey wolf optimizer (GWO) algorithm, enhanced scheduling performance and promoted sustainable shipping. Finally, Zhang et al. in 2024 addressed ship traffic scheduling problems for uncertain times of arrival and departure using a hybrid optimization approach to construct a mixed memetic algorithm with variable neighborhood search (MAVNS). This approach gently reduced waiting times, surpassing classical genetic algorithms and other scheduling methods; it demonstrates the potential of hybrid optimization methods for maritime operations. Such studies as this one demonstrate the utility of genetic and hybrid optimization techniques to optimize different aspects in maritime logistics and production scheduling, thus improving both performance and sustainability.

2.1.2 Analysis

While optimization techniques in general are well documented, the analysis presents a striking example of different methods used to tackle scheduling and operational problems encountered by maritime and shipbuilding industry. Dulebenets et al. (2018) developed a Self-adaptive Evolutionary Algorithm for berth optimization that minimizes the waiting and moving around times of the vessels and cat calls on departures. However, it was reported that this improvement came at the expense of additional computational costs, in that the time taken to run the program increased. Yin et al. (2022) developed the Iterative Variable Grouping Genetic Algorithm (IVGGA) for vessel allocation and also berth scheduling, claiming to be more efficient than orthodoxy GA methods; however, the result of this study was that the efficiency started to decline when the problems made were very extensive. Wen et al. (2024) used Multi-Objective Optimization through Grey Wolf Optimizer (GWO) for ship scheduling without compromising on environmental concerns and dealing with the problem of congestion, which is an improvement in the sustainability framework though emission control in very congested conditions was not taken into consideration. These developments are indicative of the progress in the optimization of the operations of ships with the focus on minimizing the turnaround time, optimizing the allocation of resources and achieving sustainable operation within the supply chain. However, these approaches come with difficulties as far as scalability and real-time data integration are concerned.

Author name	Technique used	Limitation	Significance
Dulebenets et al., 2018	Self-adaptive Evolutionary Algorithm	Computational time increases slightly with improved performance	Optimized berth scheduling, reducing vessel turnaround time and late departures.
Azevedo et al., 2018	Genetic Algorithm with simulation and rule-based representation	Increase in load/unload times, costs for charterers	Improved 3D Stowage Planning (SP) integrated with Quay Cranes Scheduling (SQC), reducing unplanned vessel charges.

Dong & Bian, 2020	A* Algorithm and Genetic Algorithm (GA)	Will not be scalable for very large-scale problems	Enhanced layout quality and diversity for Single-Pipe Routing Design (SPRD), effective for multiple and branch-pipe routing.
Pereire et al., 2020	Linear & Grammar-guided Genetic Programming with quantum-inspired approach	Limited to specific refinery cases	Achieved 100% success in crude oil refinery scheduling across three scenarios.
Miller, 2021	Genetic Algorithm Tuning for Ship Model Identification	Challenges in handling real-time data	Improved ship model prediction accuracy, reducing coefficient deviations for better control application fit.
Yin et al., 2022	Iterative Variable Grouping Genetic Algorithm (IVGGA)	Will underperform with large-scale problem sizes	Optimized vessel allocation and berth scheduling, surpassing traditional Genetic Algorithm (GA) efficiency even with larger problem scales.
Zhang & Qiao, 2023	Genetic Algorithm for Speed Optimization	Limited to real-time application data	Optimized ship speed for fuel consumption and weather conditions, validated by operational use.
Li et al., 2024	Self-learning Hyper-Heuristic Algorithm (GA-SLHH)	Potential complexity in dynamic learning	Solved logistics scheduling for modular cabins, improving stability and reducing transportation time by up to 37%.
Wen et al., 2024	Multi-Objective Optimization using Grey Wolf Optimizer (GWO)	Does not account for detailed emissions in high congestion	Improved ship scheduling with environmental and congestion considerations, supporting sustainability and better efficiency.

Zhang et al., 2024	Hybrid Optimization (MAVNS) combining Memetic & Variable Neighborhood Search	Will be computationally intensive in very large-scale cases	Addressed uncertainty in ship scheduling, minimizing waiting times and outperforming other optimization methods.
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2.2 Improving FRP Boat Manufacturing with Smarter Scheduling

2.2.1 Review

Improving FRP boat manufacturing with smarter scheduling has become a crucial focus to enhance production efficiency, reduce costs, and optimize material use. One promising approach is the integration of advanced technologies like genetic algorithms (GA) and optimization methods, alongside innovations in material selection and manufacturing processes. In 2019, Hamdan et al. The authors presented some fundamental aspects of the structural health monitoring (SHM) systems, e.g., ultrasonic testing, thermal imaging and acoustic emission, which can be used to determine the integrity of composite materials, e.g., fiber-reinforced polymers (FRP). Their research highlighted the possibilities for SHM in enhancing the service life and safety of FRP-based constructions, with applications across the shipbuilding sector, in particular. As measured by preventive action to improve quality control of FRP products in the field, those relating to early detection and correction of defects are in agreement here. In 2021, Lee et al. and Freitas et al. Studied the production properties of glass fiber-reinforced polymer (GFRP) laminated composites for boat hulls, with an emphasis on the application of ultrasonic nondestructive evaluation (NDE). Their results showed that laminated materials from a mixture of chopped strand mat (CSM) and wrapped roving (WR) fabrics exhibited greater quality with less voids and stronger inter-layer bonding as. These are key insights for the optimization of FRP boat structure manufacturing processes, resulting in enhanced performance and resistance. Similarly, Jang et al. 2023 drew attention to the effect of voids in composite materials on mechanical properties, emphasizing the need for high quality fabrication in ensuring safety and serviceability of boat structures. Their research suggested that optimizing laminate thickness and using combined fabrics could enhance the mechanical strength of FRP boats.

In 2023, Hu et al. Presented an optimized version of the fireworks algorithm for welding scheduling that copes with the challenges of quality related problems and production downtime. Their dynamic scheduling model, which maximizes completion time and overall order lead time, is readily applied to the FRP boat manufacturing process because such processes involve the high use of complex welding. The capability of the model to learn complex and adaptive behavior in changing environments also lends credibility to the need for more intelligent, adaptive scheduling systems. Additionally, Kim et al. in 2024 developed a hybrid optimization method combining linear programming (LP) and genetic algorithms (GA) to enhance the parallel additive manufacturing process for ship models. Their approach decreased time to completion by 14% over conventional approaches

and showed the advantages of optimization in FRP boat fabrication. Finally, the work of Oceania et al. With regard to material management in shipyards in 2024, the paper emphasizes the necessity of using a Material Requirement Planning (MRP) system to minimize manual involvement and increase procurement effectiveness. By integrating MRP systems into FRP boat production, manufacturers can streamline operations, reduce material waste, and improve product quality, ensuring that boats are built on time and within budget. These developments in materials, optimization methods, and scheduling software collectively help to increase the manufacturing of FRP hulls, by promoting more effective production and better results.

2.2.2 Analysis

The analysis of techniques used across various studies highlights their limitations, significance, and application areas. Hamdan et al. (2019) utilized Nondestructive Testing (NDT) and sensor technology for Structural Health Monitoring (SHM) in composite materials, addressing reliability challenges in aerospace, civil, and energy sectors. Despite its potential, the method was constrained by sensor limitations and environmental factors. Similarly, Lee et al. (2021) and Freitas et al. (2021) employed Ultrasonic Nondestructive Evaluation (NDE) to test GFRP composites used in ship structures, improving material quality by reducing voids. However, these methods were limited by specific laminate types and testing conditions. Kim et al. (2024) advanced Hybrid Optimization (LP & GA) for parallel additive manufacturing, improving efficiency and reducing completion time, although it struggled with scalability for larger problems. These techniques collectively underscore advancements in SHM, manufacturing optimization, material innovations, and sustainability, highlighting their transformative impact across industries despite certain limitations.

Author name	Technique used	Limitation	Significance	Application Area
Hamdan et al., 2019	Nondestructive Testing (NDT), Sensor Technology.	Limited by sensor capability and environmental factors	Explored SHM applications in aerospace, civil, and energy sectors, highlighting the potential in composite materials.	Structural Health Monitoring (SHM)
Lee et al., 2021	Ultrasonic Nondestructive Evaluation (NDE) for GFRP composites	Limited to certain laminate types and testing conditions	Improved quality and reduced voids.	Ship Structures and Materials Testing

Freitas et al., 2021	Ultrasonic Nondestructive Evaluation (NDE) for GFRP composites	Limited to a specific range of glass fiber content and laminate types	Validated combined CSM-WR laminates for improved ultrasonic NDE of GFRP composites, leading to more accurate testing results.	Ship Structures and Materials Testing
Hu et al., 2023	Improved Fireworks Algorithm for welding scheduling	Will not generalize well to other types of manufacturing	Optimized welding scheduling, improving robustness and reducing production time.	Manufacturing Scheduling
Abdulbaqi et al., 2023	Multi-objective optimization, machine learning-based algorithms.	Integration challenges in construction and higher initial costs	Demonstrated the benefits of composite materials, focusing on strength, corrosion resistance, and durability.	Civil Engineering and Construction
Minak, 2023	Reinforcement Learning (RL), Multi-objective Optimization.	Limited commercial use for specific vessel types	Reviewed and identified key areas for solar energy use in the maritime sector.	Maritime and Renewable Energy
Jang et al., 2023	Void Analysis in Composite Materials	Challenges in standardizing fabric combination types	Studied the effects of void content in composite materials, highlighting the importance of	Composite Material Testing in Ship Structures

			laminated thickness.	
Kim et al., 2024	Hybrid Optimization (LP & GA) for Parallel Additive Manufacturing	LP struggles with large problem sizes	Improving module allocation and reducing completion time.	Additive Manufacturing for Ship Models
Bhattacharya et al., 2024	Transdisciplinary Approach for Wetland Fisheries Development	Challenges with jurisdictional coordination and benefit inequity	Advanced sustainable wetland fisheries.	Sustainable Fisheries and Livelihoods
Oceania et al., 2024	Material Requirement Planning (MRP) System	Resistance to change and reliance on conventional methods	Enhancing efficiency, reducing waste, and improving product quality.	Shipyard Operations and Material Management.

2.3. Using Genetic Algorithms to Plan Boat Production

2.3.1. Review

Genetic Algorithms (GA) now play an important role in boat production planning as an effective means of increasing efficiency, lowering cost, and optimizing many aspects of the manufacturing process. Several studies have highlighted the potential of GA in addressing complex problems related to ship production, from scheduling and routing to optimizing operational efficiency. In 2020, Shen et al. Proposed a hybrid robotic fish (HRF) model for marine unmanned vehicle, in which a GA was used to tune the velocity prediction algorithm. In this approach, the results are superior to alternative prediction methods whereby the potential of GAs in finding optimal behaviour of complex dynamic systems has been shown to be of high relevance for boat production planning practices where dynamic scheduling and resource allocation are key. Alarmingly similar, in 2020 Subramanian and Jyothish applied GA to design an anti-roll tank system for ships, and optimized the design to have the smallest possible roll motion, thereby highlight the adaptability of GA in ship applications. Bacalhau et al. in 2021 applied GA to the dynamic berth allocation problem in port terminals, demonstrating its potential in optimizing resource allocation under varying conditions. The GA-based approach helped minimize service time and maximize quay occupancy, similar to how boat production scheduling can benefit from GA's ability to efficiently allocate resources and minimize delays. In another study, Zhuo and Luo in 2022 used GA to optimize tugboat operations by improving fuel consumption, demonstrating how genetic algorithms can be applied to optimize ship operations and, by extension, improve boat production processes.

In 2023, Lee et al. This paper formulated a block-assignment problem in the long-term ship production planning, and applied a two-stage metaheuristic algorithm based on GA and mixed integer linear programming (MILP) to minimize the deviation of workload and assignment cost. This approach significantly improved production planning for shipbuilders, making it a valuable application of GA in boat manufacturing scheduling. Similarly, Guzman-Ortiz et al. in the same year demonstrated the benefits of integrating production and distribution planning (PDP) with a GA and MILP model, optimizing supply chain processes for better resilience and adaptability, which are essential in the modern boat manufacturing environment. Further, Jia et al. (2024) unmanned cruise liner navigation in complex sea waters by a hybrid route planning method of a Chaos Genetic Algorithm (CWCGA), which demonstrates that GA can also be suitable for optimizing complicated trajectories. This strategy is applicable to the boats manufacturing, particularly in the optimization of the design and the scheduling and workflow of production operations. In 2024, Wu et al. tackled challenges in unmanned surface vehicles (USVs) for tasks like water sampling and garbage collection using an improved genetic algorithm, which demonstrated enhanced efficiency through reduced path lengths and redundant coverage, an approach that can be mirrored in optimizing production schedules for boat manufacturing. Additionally, Iksan et al. in 2024 utilized a hybrid GA to optimize ship routing for maritime passenger logistics, demonstrating the benefits of combining GA with other optimization techniques. This, in turn, strengthens the ability of GA for boat production planning, and efficient routing and scheduling might offer great benefits. These studies collectively illustrate how genetic algorithms can be applied across various facets of boat production, from scheduling and resource allocation to optimizing operational efficiency, ultimately enhancing the manufacturing process.

2.3.2. Analysis

The analysis highlights various optimization and computational techniques used in maritime and related industries, showcasing their strengths, limitations, and significant contributions to their respective fields. Subramanian and Jyothish (2020) employed GA to optimize anti-roll tank designs for ships. The study, validated in laboratory models, effectively mitigated vessel rolls but faced challenges with nonlinear dynamics and time-domain complexity. Zhuo and Luo (2022) utilized GA for tugboat route and speed optimization, reducing fuel consumption and providing fuel-efficient sailing plans. However, its application was limited to tugboats and specific operational conditions. Bivalkar (2024) utilized Statistical Image Analysis to improve the detection of blood vessel-like patterns in noisy medical images, enhancing diagnostic accuracy and surgical planning, though limited by noisy imaging environments. These studies demonstrate the potential of advanced algorithms in maritime operations, ship routing, and adjacent fields, despite ongoing challenges with scalability, complexity, and specific application constraints.

Author name	Technique Used	Limitation	Significance
Shen et al., 2020	GA, BPNN	Long training times and tendency to fall into local optima	Developed a velocity prediction algorithm, enhancing performance in complex ocean environments.

Subramanian and Jyothish, 2020	GA	Nonlinear dynamics and time-domain complexity	Optimized anti-roll tank design for ships, validating the method in laboratory models, demonstrating effective vessel roll mitigation.
Bacalhau et al., 2021	GA, Dynamic Programming	Computational complexity in large-scale port operations	Improved berth allocation, reducing service time and maximizing quay occupancy.
Zhuo and Luo, 2022	GA	Limited to tugboats and specific operational conditions	Reduced tugboat fuel consumption, optimized routes and speed, and provided fuel-efficient sailing plans, aiding in cost reduction.
Lee et al., 2023	Matheuristics	Computational challenges in large-scale ship production	Reduced assignment costs and workload violations, improving the planning system by integrating a two-stage matheuristic approach.
Guzman-Ortiz et al., 2023	GA, MILP	Complexities in adapting to global supply chain dynamics	Enhancing agility and resilience in supply chains, and improving relationships with customers and suppliers.
Jia et al., 2024	CWCGA, PSO	Navigational challenges in complex and dynamic water conditions	Optimized navigation for unmanned cruise liners, enhancing efficiency and pathfinding.
Wu et al., 2024	GA	Issues with irregular boundaries and repeated coverage	Improved path planning for unmanned surface vehicles (USVs), demonstrating strong adaptability and reducing redundant coverage.
Iksan et al., 2024	GA, FRNN	Complex routing challenges and large-scale logistics issues	Reduced passenger transfers and improved fitness values in ship routing.
Bivalkar, 2024	Statistical Image Analysis	Limited to noisy medical imaging environments	Enhanced detection of blood vessel-like patterns in noisy

			images, improving diagnostic accuracy and surgical planning.
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2.4. Better Scheduling for Boat Manufacturing

2.4.1. Review

Better scheduling for boat manufacturing has been highlighted as a key to improving efficiency, reducing costs and meeting sustainability targets. Many studies have proposed new methods, including integrating advanced technologies and optimization models, to improve scheduling in boat manufacturing and related industries. In 2018, Setamanit and Aem-on combined GIS with simulation to optimize crew boat scheduling in offshore oil and gas operations. By reducing the fleet size and increasing seat utilization, they achieved a significant cost reduction. The integration of GIS and simulation showed the importance of resource allocation, a principle that can be applied to boat manufacturing to improve scheduling. A year later, Azzamouri et al. introduced an interactive scheduling decision support system (ISDSS) to optimize fertilizer production on parallel heterogeneous processors. The system used a relational database for problem customization and allowed users to design solutions based on different constraints. This can be applied to boat manufacturing where scheduling and resource management can benefit from such a flexible system. In 2019, Chartron proposed a model to improve offshore logistics efficiency in wind farm construction. His model evaluated logistics strategies for different operational conditions and showed the value of adapting scheduling systems to improve cost efficiency—a concept that applies to boat manufacturing where operational variability and dynamic conditions need to be considered.

In Fang et al., (2020) also looked at better scheduling by considering the environmental impact of boat production. They proposed integrating recycled materials into the manufacturing process, encouraging more sustainable practices. Although the process was more material- and energy-intensive, this study showed the importance of considering environmental sustainability in scheduling decisions. In 2021, Song and Zhou developed a lean shipbuilding model to address long manufacturing cycles and low personnel utilization. The lean model included just-in-time production and task scheduling and resulted in significant reduction of production cycles and personnel while improving production balance. This model showed how streamlined scheduling can improve efficiency in boat manufacturing. Kolley et al. (2023) applied data-driven optimization to the berth allocation problem, using machine learning to predict vessel arrival times and reduce waiting times. This approach can also optimize boat manufacturing schedules, improve resource utilization and reduce delays. Selph et al. (2024) looked at improving boat trailer manufacturing through process optimization and better production line design. Their findings showed the value of refining processes to increase productivity, an idea that can be applied to boat manufacturing for better scheduling and efficiency. Finally, Abdeldayem et al. (2024) examined the environmental impact of vessel scheduling and showed the role of decision support systems (DSSs) in making eco-friendly decisions. By integrating such systems into boat manufacturing scheduling, companies can achieve operational efficiency and sustainability and contribute to global environmental goals. These studies

demonstrate the trend towards smarter and more efficient scheduling systems in boat manufacturing, using technology, optimization models and sustainability practices.

2.4.2. Analysis

This section analyzes various optimization techniques applied to scheduling and manufacturing in maritime and related industries, highlighting their contributions and limitations. Setamanit and Aem-on (2018) utilized GIS-based optimization and simulation algorithms to improve crew boat scheduling. Despite challenges stemming from uncertainties in employee numbers and vessel speeds, their approach effectively reduced fleet size and transportation costs. Similarly, Chartron (2019) applied heuristic methods to address turbine construction logistics, proposing adaptable strategies that reduced costs based on seasonal and locational factors, though the study identified a lack of research in the turbine construction phase. Lin et al. (2021) developed a fuzzy control system for cutting feed rate scheduling, improving machining accuracy and reducing cutting time. Despite these advancements, the technique's application was restricted to specific machining conditions. Selph et al. (2024) applied the Sawhney Model to optimize boat trailer manufacturing processes, focusing on small trailer components. This led to improved productivity and reduced cycle times. These studies showcase the growing integration of advanced optimization techniques in maritime and manufacturing sectors. They address efficiency, cost reduction, and sustainability while revealing domain-specific constraints that necessitate further exploration and refinement.

Author name	Technique used	Limitation	Significance
Setamanit and Aem-on, 2018	GIS-based optimization and simulation algorithms.	Uncertainties in employee numbers and vessel speeds	Optimized crew boat scheduling, reducing fleet size and transportation costs.
Azzamouri et al., 2019	Interactive Scheduling Decision Support System (ISDSS)	Dependency on relational databases and user interface constraints	Enhanced fertilizer production scheduling.
Chartron, 2019	Heuristic Methods	Lack of research in turbine construction phase logistics	Proposed adaptable logistics strategies, reducing costs based on season and location.
Fang et al., 2020	Multi-objective Optimization Algorithms	Higher environmental impact due to material-	Evaluated ocean plastic use in boat production, promoting sustainability through recycled materials.

		intensive processes	
Lin et al., 2021	Fuzzy Control System for Cutting Feed Rate Scheduling	Focused on specific machining conditions, limiting generality	Improved machining accuracy and reduced cutting time, enhancing manufacturing precision and efficiency.
Song and Zhou, 2021	Just-in-Time (JIT) Scheduling Algorithms	Complex implementation in large-scale operations	Reduced production cycle, labor needs, and improved production balance in shipbuilding using lean practices and virtual assembly.
Kolley et al., 2023	Predictive Machine Learning Algorithms	Dependent on accurate machine learning predictions	Enhanced berth allocation, reducing waiting times and improving service quality.
Amri et al., 2023	Macroeconomic Analysis and Design (MEAD) for Boat Production	Limited to specific production models and environmental factors	Boosted fishing boat manufacturing productivity.
Selph et al., 2024	Sawhney Model for Boat Trailer Manufacturing	Focused mainly on small trailer components	Proposed process and layout optimization, improving productivity and reducing cycle times.
Abdeldayem et al., 2024	Decision Support Systems (DSS) for Vessel Scheduling	Balancing eco-friendly methods with operational efficiency	Proposed DSS for eco-friendly vessel scheduling, reducing CO2 emissions while ensuring operational efficiency.

2.5. Making FRP Production Faster with Genetic Algorithms

2.5.1. Review

Genetic algorithms (GA) have been extensively used for the optimization of many steps of the fiber-reinforced polymer (FRP) fabrication, which results in a better efficiency, accuracy and performance for composite materials. Wang et al. (2018) used fiber Bragg grating sensors and a genetic algorithm-based sliding window peak detection technique to improve the prediction of low-velocity impacts (LVI) on FRP materials. Their method greatly enhanced the performances of peak feature extraction, providing good accuracy for the LVI localization and energy forecast, with experimental results demonstrating negligible positioning and energy forecast errors. In 2019, Al-Shalabi et al. Targeted the problem of power and network lifetime in wireless sensor networks, proposing a genetic algorithm to determine best multi-hop routes to achieve better efficiency. This novel application of GA to achieving network efficiency parallels using GA in achieving efficient production processes of FRP, which efficiency is also a priority. Specifically, Kaveh and Khavaninzadeh (2023) extended the application of genetic algorithms in predicting FRP strength by merging GA with artificial neural networks (ANNs) to achieve higher accuracy in FRP material strength prediction. By training the model on a large dataset, they achieved optimal predictions, demonstrating how GAs can refine ANN models for more precise material design and testing.

In 2024, Zhao et al. Highly optimized GFRP-concrete-steel composite columns based on a GA and ANN combination in which the GA optimized the loading capacity-to-cost ratio, demonstrating the effective synergy of GAs in material optimization. This method, validated by finite element models, proved effective for optimizing composite column designs with minimal error. The curing process of FRP composites also benefits from GA optimization, as demonstrated by Ma et al. (2024). By using a non-dominated sorting genetic algorithm (NSGA-II) they tailored the curing profile in order to minimize residual stress and cure time and thus demonstrate the application potential of GAs to improve production line and resulting material characteristics. Bhadra and Jain (2024) utilized a customized evolutionary algorithm for optimizing composite cylinders under hydrostatic pressure, achieving significant improvements in buckling resistance and a reduction in optimization time. This exemplifies how genetic algorithms facilitate complex optimization problems, ultimately leading to faster, more cost-effective manufacturing. Finally, Park et al. (2024) used a GA to tune FRP-based seismic retrofit to achieve an optimal trade-off between cost and performance for structural members. The multi-objective optimization model they used showed the power of GAs in accommodating trade-offs, thereby strengthening their position in advancing production and design processes in FRP materials. These works together demonstrate the application of genetic algorithms to optimize several steps of FRP manufacturing, ranging all the way from material strength prediction to the curing process, structural optimization, and seismic retrofitting yielding faster, more efficient, and less expensive processes.

2.5.2. Analysis

This section focuses on the assessment of different state-of-the-art optimization methods used in composite material, structural engineering, and FRP (fiber-reinforced polymer) domains – their advantages, disadvantages, and ways of optimization. Low-velocity impact location and energy detection in FRP materials has been

augmented by the use of Fiber Bragg Grating sensors with Backpropagation Neural Networks (BPNN) and Genetic algorithms by Wang et al. (2018). Accuracy of detection was high though the method is limited to low-velocity impacts. In 2020, Nguyen et al. presented a hybrid Invasive Weed Optimization (IWO) and feedforward neural network (FNN) to parameters of concrete-filled steel tube (CFST) composite which exhibited very high predictive accuracy given the complexity of the model. In 2023, Shonkwiler et al. the use of the DRL efficiency to determine the optimal laminate stacking sequences and evaluate performance was found to be superior to that of traditional methods based on maximized stiffness designs that are susceptible to specific parameters. In 2024, Park et al. used simple hybrid evolution multi objective optimization NSGA-III for expansion joints of FRP systems in seismic retrofitting design and implementation in reinforced concrete buildings which were curved limited to cost and performance goals for existing structure reinforcing and retrofitting works. These works show that optimization strategies, including evolutionary computational techniques and artificial intelligence, have a great potential in resolving issues connected with the performance and structural applications of composite materials. Though each of these methods constitutes a remarkable progress, most have limits regarding their scale, type of application or power of the models and this demands for general improvement and application of the methods on more complex problems.

Author name	Technique used	Limitation	Significance	Optimization Approach
Wang et al., 2018	Fiber Bragg Grating sensors, BPNN, Genetic Algorithm	Limited to low-velocity impacts and FRP materials	Enhanced detection of LVI location and energy in FRP with high accuracy	Genetic Algorithm-based peak detection
Al-Shalabi et al., 2019	Optimal Multi-hop Path Finding Method (OMPFM) using GA	Limited to wireless sensor networks with large distances	Improved network lifetime and power, significant reductions in node death metrics.	Genetic Algorithm
Nguyen et al., 2020	Feedforward Neural Network (FNN) with Invasive Weed Optimization (IWO)	Complexity due to CFST parameters	Achieved a high prediction accuracy.	Hybrid FNN-IWO model

Kaveh and Khavaninzadeh, 2023	Optimization of FFB and RBF ANNs using PSO, GA, CBO, ECBO	Dependence on a large set of test data points for training	Improved prediction accuracy, achieving the lowest error.	Meta-heuristic algorithms (PSO, GA, CBO, ECBO)
Shonkwiler et al., 2023	Deep Reinforcement Learning (DRL) for laminate stacking sequence	Sensitive to certain model parameters	Outperforming classical methods and achieving optimal stiffness.	Deep Reinforcement Learning (DRL)
Zhao et al., 2024	GA-ANN Optimization for GFRP-concrete-steel composite columns	Dependence on finite element modeling for ANN training	Improving the loading capacity-to-cost ratio, high accuracy and practical applicability	GA-ANN integration
Ma et al., 2024	NSGA-II and finite element simulations for cure profile optimization	Focus on macroscale and microscale stress in composites	reducing residual stress and cure time, significant improvements in Approach B.	NSGA-II, finite element simulations
Bhadra and Jain, 2024	Customized evolutionary algorithm for composite cylinder optimization	Specific to hydrostatic pressure optimization	Increased buckling resistance, and reduced computation time, significant gains in load capacity and reduced time.	Customized evolutionary algorithm
Park et al., 2024	NSGA-III for many-objective optimization in seismic retrofitting	Limited to FRP retrofitting of structural elements	Optimized FRP-based seismic retrofitting for reinforced concrete structures,	NSGA-III optimization model

			balancing cost and performance	
Faridmehr et al., 2024	ANN, GA, fmincon for shear capacity optimization of FRP-RC beams	Focused on shear capacity of beams with specific parameters	Improved shear capacity prediction, high predictive accuracy.	GA, fmincon, ANN for multi-objective optimization

3. Research gap

To achieve optimization in maritime and manufacturing operations, new approaches are needed in order to be able to address challenges such as scalability, complexity and adaptability. Yang et al. (2022) applied IVGGA: Iterative Variable Grouping Genetic Algorithm for vessel allocation and berth scheduling problem which is more efficient than classical GAs but the performance deteriorated in much larger scale problems. Likewise, Kim et al. (2024) proposed a Hybrid Optimization Strategy employing Linear Programming (LP) and Genetic Algorithms for simultaneous additive manufacturing that helped improve the make span but could not scale with even bigger datasets. Subramanian and Jyothish (2020) made use of Genetic Algorithms to solve the design issues of anti-roll tanks fitted in ships, which controlled the rolls of the vessels below a certain range although they had problems with nonlinearities and time domain issues. Chartron (2019) relied on heuristic approaches for the operational logistics of turbine construction, introducing flexible, low-cost measures but also identified lack of research in the turbine construction stage. In the same manner, Nguyen et al., (2020) combined Invasive Weed Optimization (IWO) developed Hybrid Feedforward Neural Network for optimization of the parameters of Composite-Filled Steel Tubes (CFST), which demonstrated a high level of precision at the expense of model complication. Therefore, there is a need to construct new types of optimization frameworks that would be efficiently and easily scalable to different industries.

4. Conclusion

To sum up, the use of genetic algorithms in the processes of Fiber-Reinforced Polymer (FRP) boat construction is a modern way of improving the production planning process. In dealing with such issues as task overlap, limited resources, and management of operational hindrances in any process, genetic algorithms, as a technique, are flexible, effective, and exceed almost all the other techniques. The implementation of the GA-based model in the present study proves to be useful in minimizing lead times, improving the utilization of resources, and boosting production efficiency. These findings prove the potential of genetic algorithms to transform the FRP boat manufacturing processes through faster, smarter, and greener production systems. This method solves even the present-day needs of the industry but also lays the groundwork for future undertakings on how to enhance manufacturing flexibility and efficiency.

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