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A Review of Systematic Methodologies for Shipyard Facility Layout Design

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Abstract

The dynamic and complex nature of the shipbuilding industry necessitates efficient facility layout planning to optimize operational efficiency and minimize costs. Traditional layout design approaches, often based on practical experience, fall short of achieving optimal results. This paper reviews three advanced methodologies for shipyard facility layout design: heuristic algorithms, Systematic Layout Planning (SLP), and graph theory. Heuristic algorithms, including genetic algorithms and simulated annealing, offer flexible and rapid solutions but may not always achieve global optimization. SLP provides a structured and methodical approach, ideal for stable environments, yet lacks flexibility in dynamic settings. Graph theory enhances the layout design process by optimizing spatial relationships between facilities through weighted planar graphs. The study highlights the strengths and limitations of each method, with a focus on their impact on material handling costs and overall layout efficiency. Among these, the combination of Genetic Algorithms (GA) and Stochastic Growth Algorithms (SGA) stands out, demonstrating significant reductions in material handling costs, up to 23.1%. The review concludes that while each methodology has its merits, the integration of GA and SGA offers the most robust solution for optimizing shipyard layouts, particularly in complex and large-scale environments. Future research should explore hybrid models that combine these methodologies, incorporating advanced computational techniques and real-time data analytics to create more dynamic and adaptable layout solutions, addressing the evolving needs of the shipbuilding industry.

1. Introduction

The shipbuilding industry is highly sensitive to fluctuations in global trade, with demand varying drastically over relatively short periods. A significant example occurred between 2005 and 2008 when the industry experienced an unprecedented surge in orders, driven by a substantial increase in seaborne cargo traffic as global trade volumes expanded. This period marked historic highs in shipbuilding orders, highlighting the industry's responsiveness to changes in trade dynamics [1]. The rapid escalation in demand during these years underscored the critical need for efficient shipyard operations [2], where optimizing the sequence of tasks and processes becomes essential for reducing production time and meeting delivery schedules. The efficiency of the production process is significantly influenced by the strategic organization of the shipyard. By carefully optimizing the placement of each shop and work stage, taking into account crucial factors such as material flow, relational dynamics between stages, and associated costs, the overall sequence of production tasks can be greatly streamlined. This thoughtful arrangement not only leads to reduced production times but also enhances operational efficiency across the board. Ultimately, the implementation of a well-designed layout brings these benefits to fruition [3].

Historically, the design of shipyard layouts has relied mainly on the practical experience and expertise of industry professionals rather than on structured design methodologies. This conventional approach often results in less-than-optimal layouts, failing to harness the full efficiency potential that systematic, algorithm-driven planning techniques can offer [4]. An effectively designed shipyard layout strives to maximize operational efficiency while minimizing costs by optimally arranging spatial resources and waterfront facilities to align seamlessly with the system's workflow [5]. Material handling costs (MHC) are a significant concern in shipbuilding [6], accounting for approximately 20% to 50% of operating expenses. The shipbuilding industry, characterized by heavy steel and large intermediate products, particularly suffers from high MHC. Optimizing the facility layout is thus not only a matter of improving operational efficiency but also a critical strategy for reducing production costs. Research indicates that effective layout optimization can reduce these costs by 10% to 20%, making it an urgent priority for shipyards.

Recent advancements in layout optimization methodologies, such as heuristic approaches, Systematic Layout Planning (SLP), and Graph Theory, offer various advantages for addressing the specific challenges of shipyard layout planning. For instance, heuristic methods have been successfully applied in other manufacturing environments and show promise for adaptation to shipbuilding. SLP provides a structured methodology for arranging spatial resources, while Graph Theory offers a mathematical framework for optimizing connections between different areas of the shipyard. Simulation and optimization techniques, particularly those based on genetic algorithms and stochastic growth algorithms, have proven effective in improving shipyard layout planning. These methods can lead to significant productivity gains by optimizing the sequence of tasks and reducing production times. For example, genetic algorithms have been applied successfully in shipbuilding workshops to find the best sequences for minimizing production times, demonstrating gains of over 8% in efficiency.

The objective of this research is to compare the effectiveness of Heuristic, Systematic Layout Planning (SLP), and Graph Theory methodologies in optimizing shipyard layouts. The study aims to identify which method best reduces material handling costs, enhances workflow efficiency, and improves overall production efficiency within the shipbuilding industry. By conducting a comparative analysis of these methodologies, this research provides actionable insights that can be directly applied to shipyard operations, potentially leading to significant cost savings and productivity improvements. Furthermore, this research intends to bridge a gap in the existing literature by offering a detailed evaluation of these three layout planning methodologies within the context of shipyard operations. The anticipated outcomes of the study include a better understanding of the strengths and limitations of each method, enabling shipyard operators to make informed decisions regarding layout design and optimization. Ultimately, the findings are expected to contribute to the broader field of industrial facility layout planning, offering valuable guidance for optimizing layouts in complex production environments such as shipbuilding.

2. Shipyard Facility Layout Design

The design of a shipyard facility layout involves a structured approach to arranging and organizing physical facilities within a shipyard to enhance production efficiency, lower costs, and meet stakeholder needs [7]. The goal of an effective shipyard layout design is to streamline workflow, minimize unnecessary material and personnel traffic, and reduce material handling costs (MHC), which represent a significant portion of the overall production expenses [8]. According to research, MHC can account for 20% to 50% of operating costs in shipbuilding and an optimized layout can reduce these costs by 10% to 20%, underscoring the importance of systematic planning in shipyard operations.

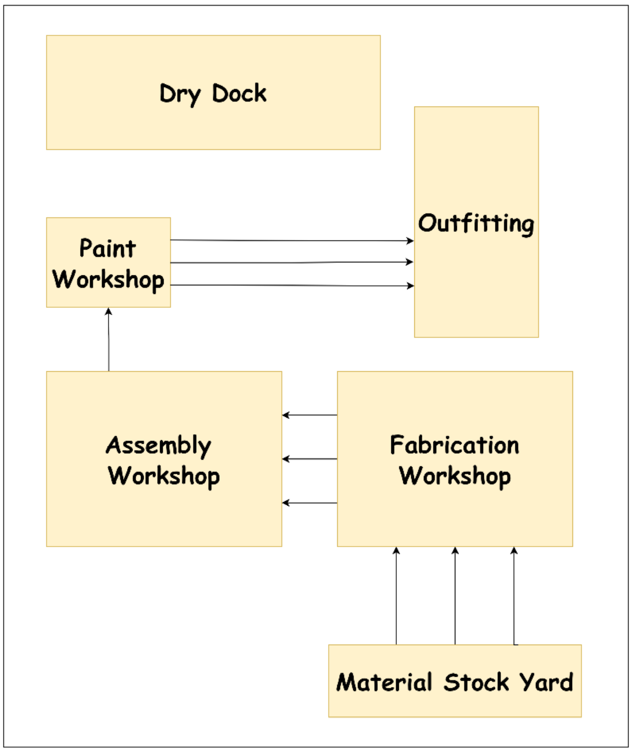

Figure 1. Basic Shipyard Facility Layout

Most shipyards do not benefit from being established on a 'greenfield' site, a completely undeveloped area ideally located in a harbor or port, which would allow for an ideal layout from the start. Instead, many shipyards are constrained by existing geographic and infrastructural limitations, requiring modifications to production flow lines as the facility expands. Typically, shipyards begin by building smaller vessels and gradually expand their operations. Figure 1 illustrates a basic layout of a shipyard, highlighting primary components such as the material stock yard, fabrication, assembly, painting, outfitting, and dry dock. Each of these facilities represents a critical part of the ship production process. For example, secondary components in the fabrication process include cutting area, straightening area, bending area, and so on [9].

2.1. Research for Shipyard Facility Layout Design

Over the past two decades, several methods have been developed for Facility Layout Planning (FLP) in the context of shipyards, primarily aimed at enhancing operational efficiency and reducing Material Handling Costs (MHC). These methods have been adapted from general FLP research within operations research and industrial engineering. Given the limited number of studies directly addressing shipyard layout design, this systematic review focuses on research and case studies, as these types of studies provide the most detailed and applicable insights for shipyard layout optimization.

This review was conducted using a Systematic Literature Review methodology, adhering to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [10], [11] to ensure that systematic reviews are conducted and reported transparently and thoroughly. The initial search identified numerous studies relevant to shipyard facility layout design. However, to ensure the relevance and quality of the review, the selection was narrowed down to studies classified as either research studies or case studies, focusing specifically on those that address MHC as a key factor in shipyard layout optimization. The filtering process began with an extensive search across academic databases, yielding over 50 studies. Only research studies and case studies were included, as these provide practical and empirical insights. Studies had to specifically address shipyard layout design with a focus on MHC. Preference was given to studies employing systematic methodologies such as Heuristic Algorithms, Genetic Algorithms, Stochastic Growth Algorithms, Evolutionary Algorithms, Systematic Layout Planning (SLP), and Graph Theory. After applying these criteria, the review was narrowed to six key studies, as summarized in Table 1. These studies represent the most significant contributions to the field, providing insights into different methods for optimizing shipyard layouts to reduce MHC. As shown in Table 1, several studies have focused on minimizing material handling costs, a critical factor in shipyard operations. This emphasis is justified, given that MHC represents one of the largest expenses in ship production.

Table 1. Research on Shipyard Facility Layout

Author and Year	Objectives	Methods	Time and Iteration	Advantages	Disadvantages
Lee et al. (2013) [12]	Optimizing the size and shape of layout modules and their arrangement to enhance productivity and reduce material handling costs	Heuristic Algorithm	Moderate with multiple iterations	High adaptability to specific constraints	May not reach global optimal solution
Choi et al. (2017) [4]	Minimize a material handling costs which also optimizing the adjacency and alignment of different departments	Genetic Algorithm & Stochastic Growth Algorithm	High with 1000 generations	Effective for complex layouts	Requires significant computational resources
Azzolini et al. (2019) [13]	Minimize material handling costs in shipyard and improve overall layout efficiency	Evolutionary Algorithm	Variable and multiple with several generations	Flexibility in handling multiple objectives	Complex to implement
Gunawan et al. (2021) [14]	Minimize material handling costs in shipyard	Genetic Algorithm	High with up to 1000 generations	Robust solution for non-linear problems	Can be time-consuming
Azzolini et al. (2023) [9]	Optimize a shipyard facility layout by considering departments' closeness conditions to minimize material handling costs	Genetic Algorithm & Stochastic Growth Algorithm	High with multiple iterations	Balances multiple constraints effectively	Computational intensity
Tamer et al. (2023) [8]	To enhance shipyard production efficiency by optimizing the adjacency of departments	Systematic Layout Planning (SLP) & Graph Theory	Moderate with limited iterations	Structured approach to spatial resource allocation	Limited flexibility in dynamic environments

2.2. Methods

Based on the studies summarized in Table 1, the following systematic methods are reviewed being classified into three main types: Heuristic Algorithms, Systematic Layout Planning (SLP), and Graph Theory. These methods are increasingly being integrated into shipyard layout design processes to address the industry's complex and dynamic nature. Figure 2 outlines these methods and their associated techniques, such as Evolutionary Algorithms and Genetic Algorithms, which are used to further refine and optimize shipyard layouts also increasingly integrated into shipyard layout design processes to address the industry's complex and dynamic nature. The three main methods include heuristic algorithms, systematic layout planning, and graph theory. Each of these methods has its own characteristics, which will be explained in the following section.

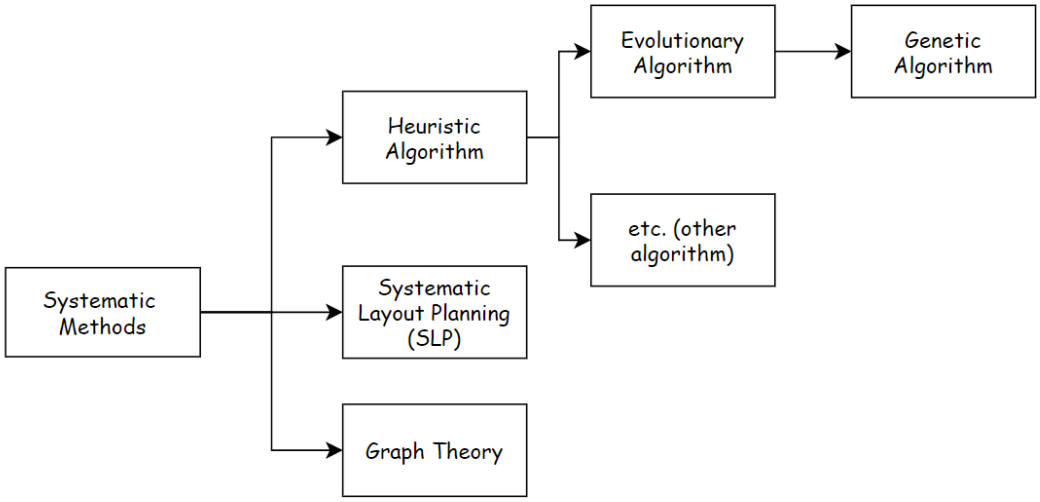

Figure 2. Systematic Methods

2.2.1. Heuristic Algorithm

A heuristic algorithm is a method designed to provide approximate solutions to complex optimization problems where finding an exact solution is impractical due to constraints in time or resources. Unlike exact algorithms that ensure the discovery of the optimal solution, heuristic algorithms focus on finding a sufficiently good solution within a reasonable timeframe [15]. These algorithms rely on strategies derived from experience, intuition, or established guidelines to guide decision-making during the search process. In Facility Layout Planning (FLP), heuristic methods are particularly valued for their flexibility and speed in generating solutions, making them highly effective in scenarios where quick, practical solutions are necessary [16]. However, their inherent limitation is that they may not always reach the global optimal solution, which can diminish their effectiveness in particularly complex or large-scale layout problemss [17], [18]. Several researchers have conducted FLP studies using various heuristic methods, including genetic algorithms [19], [20], simulated annealing [21], [22], tabu search [23], ant colony optimization [24], [25], particle swarm optimization [26], [27], etc. Specifically, in the context of FLP, including shipbuilding operations, the core mechanism of heuristic methods involves randomly altering the arrangement of workshops while following the guidelines or principles of the respective heuristic method.

Genetic algorithms (GAs) are particularly effective for FLP due to their capability to explore vast solution spaces and converge towards optimal or near-optimal layouts [28], [29]. For example, a study by Azadivar and Wang [30] demonstrated how GAs, when combined with simulation, can optimize facility layouts by minimizing both material handling costs and production cycle times. This approach was particularly useful in real-world manufacturing environments, where dynamic system characteristics and operational constraints are common [31]. Similarly, Deep et al. [32], used a GA-based approach to tackle the Quadratic Assignment Problem (QAP) in FLP, focusing on reducing the frequency of material handling among different facilities. The genetic operators in this GA, such as crossover and mutation, were designed to maintain solution diversity and enhance the search for global optima. The results indicated that the GA-based approach outperformed traditional heuristics, achieving significant reductions in material handling costs while maintaining computational efficiency.

Simulated annealing is another heuristic method notable for its effectiveness in dynamic facility layout problems [33]. Turgay [34] developed a simulated annealing heuristic that optimized layouts over multiple periods by minimizing the total of material handling and re-arrangement costs. This method proved effective in generating near-optimal solutions with reduced computational time. Furthermore, other studies have enhanced the efficiency and quality of simulated annealing by integrating it with hybrid methods, such as a hybrid ant system.

For instance, research by Chen [35] highlighted the use of a hybrid ant colony optimization (ACO) technique in addressing large dynamic facility layout problems. The study found that by improving the data structure of solution representation, significant improvements were made in both computational time and solution quality. Specifically, the ACO achieved up to a 7.25% improvement in solution quality for large-scale layout problems, such as those involving 30 departments over 10 time periods, compared to traditional methods. Similarly, a study conducted by Samarghandi et al. on the use of Particle Swarm Optimization (PSO) for the Single Row Facility Layout Problem (SRFLP) demonstrated that PSO could efficiently handle the problem's complexity by mapping the discrete feasible space to a continuous space. The computational results from benchmark problems showed that the proposed PSO algorithm significantly outperformed other heuristics in terms of solution quality and computational efficiency, with the PSO achieving near-optimal solutions in less time [36].

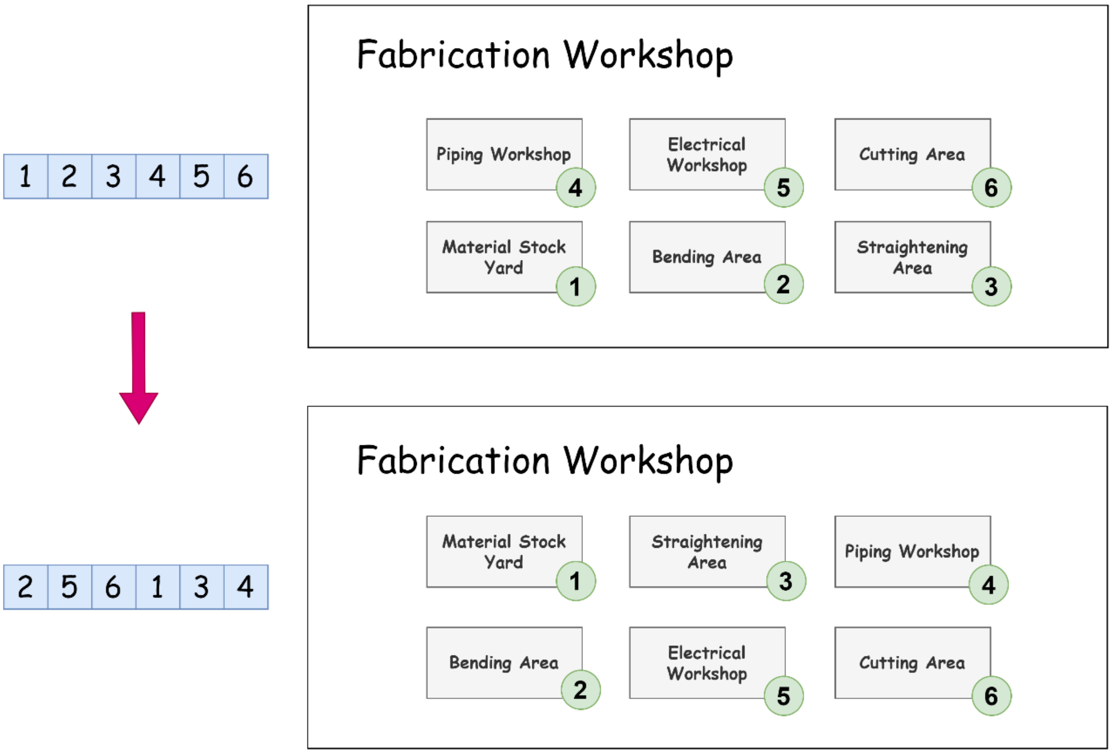

Figure 3. Example of Heuristic Step

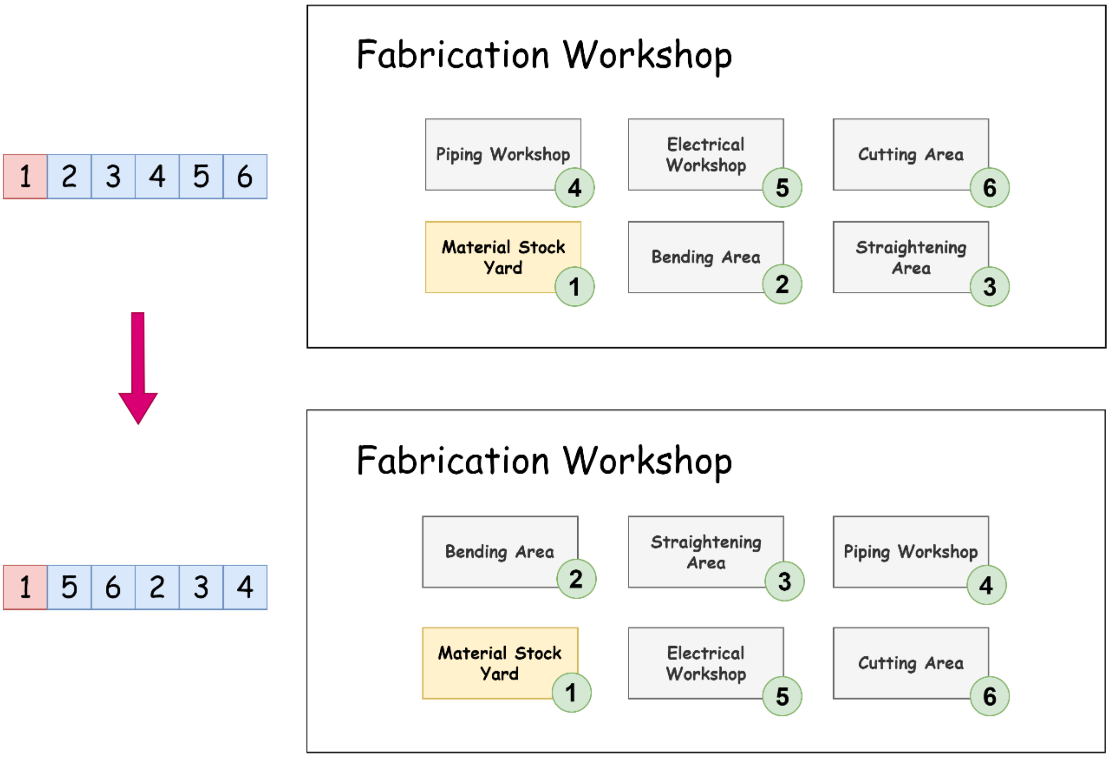

Figure 4. Extension model of placement

In the context of shipbuilding operations, heuristic methods typically involve rearranging workshops within the facility layout, adhering to the specific guidelines of the chosen heuristic method. For example, as illustrated in Figure 3, a heuristic step might involve repositioning workshops within a fabrication area to optimize workflow and reduce material handling costs. However, certain workshops, such as the material stockyard, may need to remain in a fixed position due to operational constraints, as depicted in Figure 4. This adds an additional layer of complexity to the layout planning process, requiring the heuristic method to navigate around these fixed elements while still striving for overall optimization.

Various studies have utilized different heuristic methods for FLP, including genetic algorithms, simulated annealing, tabu search, ant colony optimization, and particle swarm optimization. These methods each have unique strengths and are selected based on the specific needs and constraints of the layout problem. For example, a study by Chen [35] also demonstrated that by using a binary coded hybrid ant system (BC-HAS), significant reductions in computational time were achieved without sacrificing solution quality. The BC-HAS method was found to be 3 to 8 times faster than other benchmarked heuristics for large-scale problems. Additionally, research on tabu search by Dbouk et al. [23] found that this method was particularly effective in solving facility layout problems in manufacturing systems. The tabu search method was able to find solutions that were within 1.5% of the best-known solutions while requiring significantly less computational time compared to genetic algorithms and simulated annealing. In summary, while heuristic algorithms may not always find the absolute best solution, their ability to quickly provide good enough solutions makes them valuable tools in facility layout planning, particularly in dynamic and resource-constrained environments like shipbuilding. Their application can lead to significant improvements in layout efficiency, although careful consideration must be given to the specific method chosen and the constraints of the particular problem being addressed.

2.2.2. Systematic Layout Planning

Systematic Layout Planning (SLP), first introduced by Muther in 1950s [37], is a method designed to arrange and optimize the layout of manufacturing facilities. Its main objective is to enhance the facility's efficiency and productivity by minimizing waste, improving workflow, and reducing the travel distance for materials and products [38]. SLP is a structured and methodical approach that can be applied to various types of facilities, including factory, warehouses, and distribution centers. Many researchers have utilized SLP in their studies for FLP cases across various applications [39], [40].

The SLP process begins with the collection of essential data related to products, quantities, processes, supporting services, and timing (PQRST) [41]. The subsequent step involves analyzing the flow of materials and creating relationship charts to determine the necessary proximity of different activity areas. Space requirements are then calculated, and a space relationship diagram is constructed to visualize these spatial relationships. Various layout alternatives are generated and adjusted based on practical constraints, followed by evaluation using criteria like cost and efficiency. The optimal layout is then selected, and detailed plans are developed, specifying the exact location of equipment and activity areas. Finally, the installation process is planned to ensure a smooth implementation. This comprehensive approach ensures that all relevant factors are considered, resulting in an efficient and productive facility layout [37], [42].

In SLP, determining the appropriate closeness ratings between various workshops is essential to ensure efficiency and productivity. The closeness rating helps in understanding how near or far each workshop should be from one another based on their interdependencies and workflow requirements. The different classes of closeness ratings and their significance are as follows:

- **A (Absolutely necessary):** This rating indicates that two workshops must be very close to each other due to high interaction and frequent material or information exchange. Proximity is crucial to minimize transportation time and cost and to enhance workflow efficiency.
- **E (Especially important):** Workshops with this rating should be near each other because they have significant interactions. While not as critical as the "A" rating, their closeness greatly benefits overall efficiency and productivity.
- **I (Important):** This rating denotes that it is beneficial for the workshops to be relatively close. Their operations are interconnected, and proximity can improve coordination and reduce delays.
- **O (Ordinary closeness):** This rating suggests that while it is useful for these workshops to be near each other, it is not critical. Moderate distance is acceptable, and operations can still proceed efficiently.
- **U (Unimportant):** Workshops with this rating do not need to be close to each other. Their interactions are minimal, and distance does not significantly impact their operations.

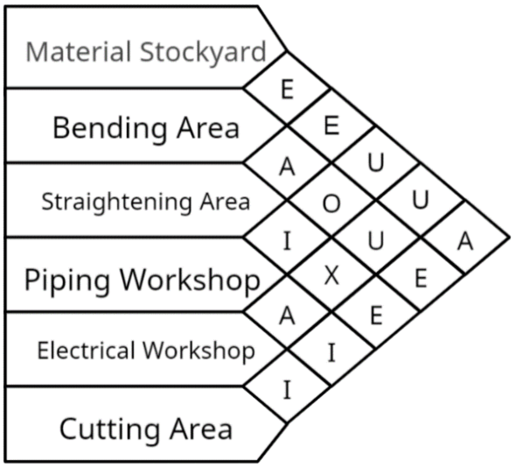

Figure 5. Relationship Chart in Shipyard Workshops

Figure 5 illustrates a relationship chart between shipyard workshops, showing the closeness ratings and their importance. The relationship chart serves as a foundational tool in SLP to visually represent the necessary proximity of different workshops based on their interactions and dependencies.

After determining the relationship chart, SLP progresses to the creation of a space relationship diagram, as shown in Figure 6. The space relationship diagram visually maps out the spatial requirements and relative positions of each workshop, ensuring that the physical layout of the facility aligns with the desired proximity ratings. This diagram serves as a blueprint for generating various layout alternatives that closely align with the defined spatial relationships. These alternatives are evaluated, and the most efficient layout is selected for implementation. By following these steps, SLP ensures that the final layout maximizes operational efficiency, minimizes material handling costs, and optimizes the use of available space, ultimately contributing to the facility's overall productivity and effectiveness.

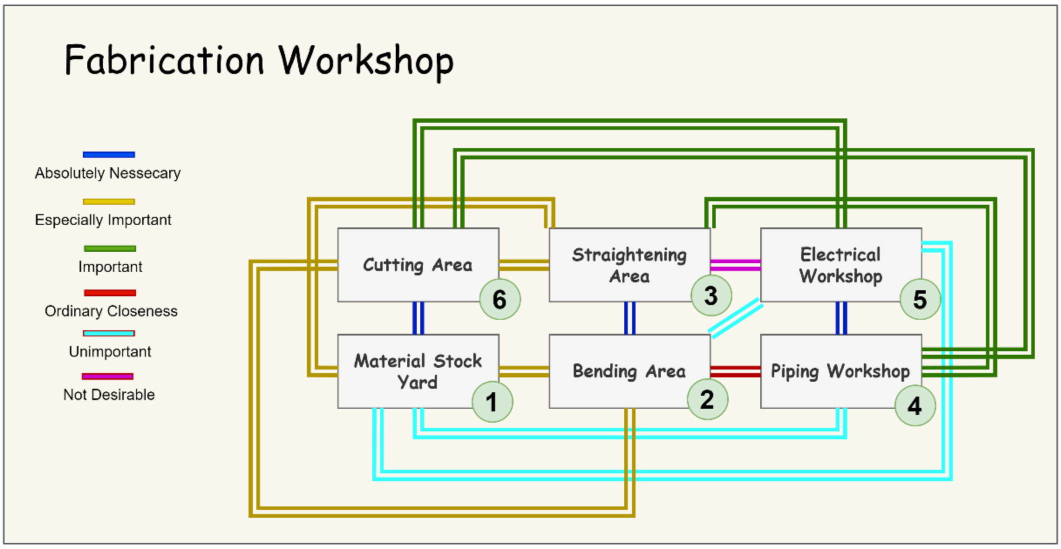

Figure 6. Space Relationship Diagram

2.2.3. Graph Theory

The graph theory approach for shipyard facility layout design begins by creating an adjacency graph that visually represents the relationships between different departments. Each department is depicted as a node, and the interactions or closeness between them are shown as weighted edges. The weight of each edge reflects the importance or frequency of interactions between departments, which is essential for minimizing material handling costs and maximizing operational efficiency. By defining the order of nodes and identifying their optimal locations, this method produces a maximal planar weighted graph with a limited and known number of edges, ensuring the most critical departments are placed adjacent to each other [43], [44].

The graph-theoretical approach involves several steps. Initially, a relationship chart is created and converted into numerical values, representing the closeness ratings between departments. This chart helps to generate a maximal planar adjacency graph, which is then used to develop feasible layout alternatives. The objective is to maximize the sum of the closeness ratings of adjacent department pairs, thereby ensuring the layout supports efficient material flow and reduces handling costs. In practice, the adjacency graph guides the arrangement of departments, prioritizing those with higher interaction frequencies to be closer together. Then the adjacency graph is refined using graph-theoretic techniques to ensure that all facilities are optimally placed according to their interaction weights [45]. By systematically arranging facilities based on their interaction priorities, graph theory provides a robust framework for optimizing complex facility layouts, like in shipyards.

The graph-theoretical approach involves several key steps. Initially, a relationship chart is created, which categorizes the required closeness between different facilities using letter ratings (A, E, I, O, U, X). This chart is then converted into numerical ratings for quantitative analysis, where 'A' is converted to 8, 'E' to 4, 'I' to 2, 'O' to 1, 'U' to 0, and 'X' to -8 . Figure 7 illustrates how these relationship charts are converted into numerical ratings [8].

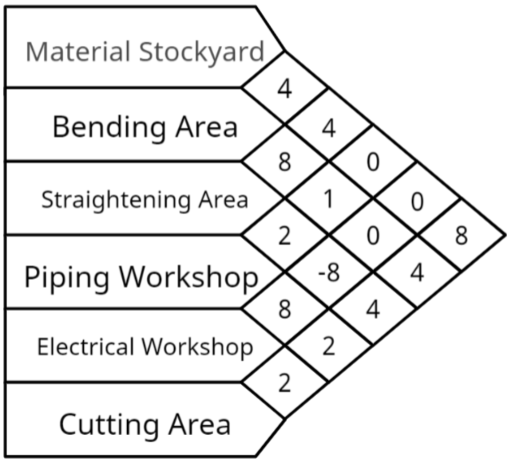

Figure 7. Relationship Charts Converted to Numerical Ratings

The core of the graph theory method involves iteratively searching for the maximum value in a planar graph based on these numerical ratings. This process ensures that the final layout is optimized for efficiency and minimal material handling costs by continuously adjusting and refining the arrangement of nodes (facilities) and edges (connections). The goal is to achieve a configuration where the total interaction weights are maximized without violating the planarity constraint, thus creating the most effective facility layout. For instance, in Figure 8, an example of a planar graph for a fabrication workshop layout is presented. This graph represents the spatial arrangement of workshops based on their interaction weights. The total weight in this example is 43, indicating the sum of all closeness ratings between adjacent departments. After constructing the planar graph, it is then converted into an actual layout, as shown in Figure 9. This layout visually represents the optimal arrangement of workshops, ensuring that those with the highest interaction frequencies are placed nearest to each other. It is important to note that in the final layout, workshops not connected by lines in the planar graph can still be adjacent or touching. However, workshops connected by lines in the graph, especially those with high numerical values, must be placed close to each other to maintain efficiency. This systematic arrangement of facilities based on their interaction priorities enables graph theory to provide a robust framework for optimizing complex facility layouts, such as those found in shipyards.

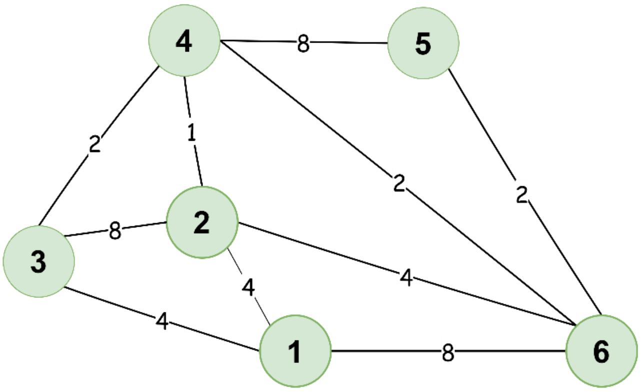

Figure 8. Example of Planar Graph

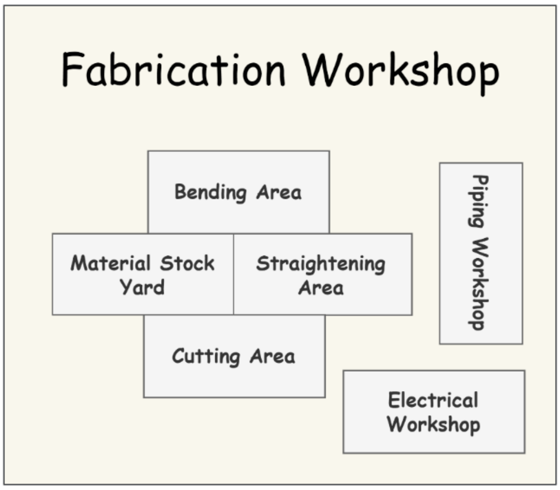

Figure 9. Converted Layout from Planar Graph

3. Results and Discussion

The shipbuilding industry is highly dynamic, characterized by complex production processes that require efficient facility layout planning to minimize costs and maximize operational efficiency. Traditional approaches, which often rely heavily on practical experience, have been found lacking in achieving optimal results. This shortcoming has led to the exploration and implementation of more systematic methodologies to improve the design and operation of shipyard facilities. Among the popular tools in facility layout planning (FLP) are heuristic algorithms, such as genetic algorithms and simulated annealing. These methods have gained traction due to their flexibility and ability to rapidly generate near-optimal solutions. Heuristic algorithms iteratively refine the arrangement of facilities by adjusting the layout based on specific rules and constraints. For instance, genetic algorithms (GAs) are particularly effective in exploring large solution spaces and converging towards optimal or near-optimal layouts. Studies, including those by Azadivar and Wang, have demonstrated the effectiveness of GAs in minimizing material handling costs and production cycle times when combined with simulation techniques. However, heuristic algorithms generally provide only moderate improvements in layout efficiency (15-20%) and are not guaranteed to reach a global optimal solution, which limits their effectiveness in large-scale or highly complex layout problems.

Another widely used methodology is Systematic Layout Planning (SLP), introduced by Muther, which offers a structured approach to optimizing facility layouts by systematically collecting and analyzing data on products, quantities, processes, and spatial requirements. The SLP process involves creating relationship charts to determine the necessary proximity of different workshops, ensuring an efficient and productive layout. This is followed by the creation of a space relationship diagram, which visually represents the spatial requirements and relative positions of each workshop, guiding the generation and evaluation of layout alternatives. While SLP is particularly advantageous in stable and predictable environments, its main drawback lies in its limited flexibility in dynamic or rapidly changing environments that may require frequent layout adjustments.

Graph theory also plays a significant role in enhancing the layout design process by representing the relationships between facilities as a weighted planar graph. This approach ensures that workshops with critical interactions are positioned adjacent to each other, thereby maximizing operational efficiency. The method involves converting qualitative relationship data into numerical values, which are then used to create adjacency graphs. These graphs guide the optimal arrangement of facilities, and their iterative refinement ensures that the final layout maximizes the sum of interaction weights while maintaining planarity. Despite its strengths, the application of graph theory, similar to SLP, may be less effective in environments that require a high degree of flexibility. Table 1 provides a comparative overview of the different methods employed in shipyard facility layout design, including Heuristic Algorithms, Genetic Algorithms (GA), Stochastic Growth Algorithms (SGA), Evolutionary Algorithms (EA), Systematic Layout Planning (SLP), and Graph Theory. Each method is evaluated based on its objectives, methodologies, advantages, disadvantages, efficiency, and the time and iteration requirements necessary to achieve optimal results.

Genetic Algorithms (GA) and Stochastic Growth Algorithms (SGA) stand out as powerful tools for minimizing material handling costs (MHC) and optimizing the adjacency and alignment of departments within a shipyard. These methods are particularly effective in navigating large search spaces to find optimal solutions, especially in complex layout scenarios. For example, a study by Choi et al. demonstrated that GA and SGA could achieve a 23.1% reduction in MHC, highlighting their efficiency in optimizing shipyard layouts. However, the main disadvantage of these algorithms is their high computational resource requirement, making them time-consuming and sometimes impractical for real-time applications. Nevertheless, their ability to handle complex and non-linear problems makes them invaluable in scenarios where precision and optimization are critical.

Evolutionary Algorithms (EA) share similarities with Genetic Algorithms but are often used in multi-objective optimization problems. They offer the flexibility to handle multiple constraints and objectives simultaneously, making them suitable for shipyard layouts that require a balance of factors such as cost, space, and workflow efficiency. The strength of Evolutionary Algorithms lies in their capacity to find solutions that balance multiple criteria effectively. However, their complexity and the need for careful parameter tuning can be challenging. Despite these challenges, Evolutionary Algorithms can achieve an efficiency improvement of 20-25%, making them a robust choice for shipyard layout planning.

In conclusion, the integration of heuristic algorithms, Systematic Layout Planning (SLP), and graph theory provides a comprehensive framework for optimizing shipyard facility layouts. Each of these methodologies contributes unique strengths that enhance efficiency, reduce material handling costs, and streamline production workflows. However, considering the factors outlined in Table 1 such as efficiency, computational resource requirements, and flexibility. The Genetic Algorithm (GA) combined with Stochastic Growth Algorithm (SGA) emerges as the most valuable method for shipyard facility layout design. Despite its high computational demands, GA′s ability to handle complex, non-linear problems and its proven effectiveness in significantly reducing material handling costs (up to 23.1%) make it the most robust option. This approach not only addresses the complexities of modern shipyard layouts but also provides a scalable solution that can adapt to the evolving demands of the industry, ensuring long-term operational success. Future research should consider developing hybrid models that combine these methodologies to further leverage their advantages. Additionally, incorporating advanced computational techniques and real-time data analytics could offer more dynamic and adaptable layout solutions, addressing the evolving demands of the shipbuilding industry

4. Conclusion

The review of shipyard facility layout methodologies highlights the significant role of systematic approaches in optimizing layout efficiency and reducing material handling costs. Heuristic algorithms, Systematic Layout Planning (SLP), and graph theory each offer distinct advantages and limitations. Heuristic algorithms are valued for their adaptability and speed, although they may not always achieve global optimization. SLP provides a structured approach ideal for stable environments but lacks flexibility in dynamic settings. Graph theory, while effective in optimizing interactions between facilities, can be complex to implement and may struggle in rapidly changing environments. Among these, Genetic Algorithms (GA) combined with Stochastic Growth Algorithms (SGA) emerge as the most robust method, particularly for complex, large-scale shipyards. This combination has demonstrated significant reductions in material handling costs, up to 23.1%, making it a valuable tool for optimizing shipyard layouts. Future research should focus on developing hybrid models that integrate these methodologies, leveraging their combined strengths to address the evolving demands of the shipbuilding industry. Additionally, incorporating advanced computational techniques and real-time data analytics will be crucial for creating more dynamic and adaptable layout solutions, ensuring long-term operational success.

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