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Classification of Facility Layout Problems

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A B S T R A C T

The Facility Layout Problem (FLP) is a critical aspect of production and operations management, aiming to optimize the spatial arrangement of departments or facilities within manufacturing and service environments. The primary objective is to minimize material handling costs; which can account for up to 50% of total operating expenses in some industries; by reducing the distance traveled between facilities weighted by their interaction frequency. A well-designed layout significantly impacts key performance indicators such as productivity, throughput time, space utilization, and workflow efficiency. FLPs are inherently complex combinatorial optimization problems, often classified as NP-hard, due to the numerous constraints involved, including unequal department areas, adjacency requirements, and dynamic changes over time. Various layout configurations have been explored, such as single-row, multi-row, loop, open-field, and multi-floor arrangements, each offering distinct advantages depending on the application context. Exact methods, heuristic algorithms, and especially metaheuristics like genetic algorithms and simulated annealing have been widely employed to tackle these challenges. Hybrid approaches combining different optimization techniques have also shown promise in solving large-scale real-world instances. Beyond cost reduction, modern FLP studies increasingly emphasize ergonomics, safety, flexibility, and sustainability in layout design. As industries evolve with new technologies and fluctuating demands, adaptive and intelligent layout planning becomes essential for maintaining competitive advantage. This paper provides a comprehensive overview of FLP classifications, objectives, and solution strategies, highlighting its significance in both theoretical research and practical implementation across diverse sectors.

Keywords

Facility Layout Problem (FLP), Dynamic Layout, Space Utilization, Layout Configuration

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1. Introduction

The Facility Layout Problem (FLP) is an important research stream within production research. An FLP is defined as the search for the most efficient arrangement of departments, i.e. facilities, in a plant area subject to different constraints while attempting to satisfy one or more objectives. FLPs can be located on the tactical hierarchical layer in organizations, provoking the assumption that sound decisions on facility layouts constitute a significant contribution to economic success of manufacturing companies (Burggraf et al, 2024). Facility Layout Problem (FLP) deals with arranging various facilities of a manufacturer, plant, company, or organization in the most effective way to allow greater efficiency in the combination of resources to produce a product. The layout problem is one of the obvious and complex NP-Hard problems, which integrate multidimensional issues and information in one model or problem. Practically and economically, for U.S. manufacturers, material handling costs 50% of total operating expenses in some cases. Appropriate facility design can reduce these costs by at least 30%; these issues represent more than $250 billion per year assigned to the design of facility systems, layouts, handling systems, and facility locations (Al-Zubaidi et al, 2021).

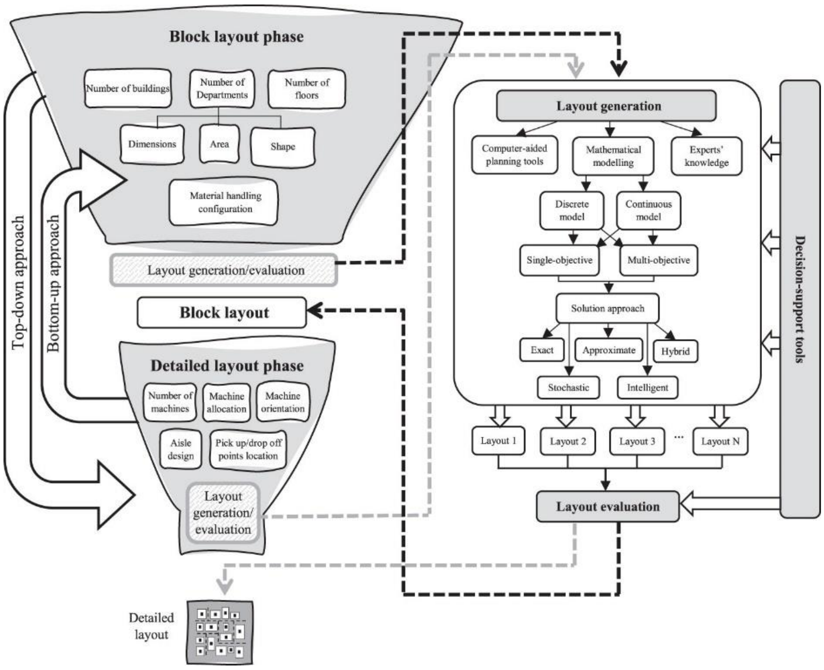

Fig. 1. FLP General Framework (Peres-Gosende et al, 2021).

Numerous variants of the FLP problem have been formulated and researched. They can be categorized by different aspects as static or dynamic FLP, single- or multi-objective FLP, single- or multi-floor FLP, or FLP with equal or unequal facility areas, etc. When considering facility characteristics, several factors and design issues are addressed in the literature, such as the production variety and volume, the facility shapes and dimensions, the material handling system chosen, and different possible movement types allowed for parts, to name a few. Regarding the shapes and dimensions, there are two types of facilities: facilities with regular rectangular shapes and those with irregular shapes, i.e., generally polygons. In the former case, a facility can be defined by fixed length and width, and this facility is called fixed or rigid block. An important FLP variant with numerous practical uses is the FLP with loosely-defined facility shapes and dimensions. In that case, each facility is associated with its area and a shape constraint, e.g., the maximum aspect ratio allowed (quotient between greater and lesser side measurements) or the minimum side length (Kubalik et al, 2023).

2. Facility Layout Problem Classification

2.1. Based on Time Horizon

Facility layout planning (FLP) is a critical aspect of industrial production systems, as it involves a set of design problems related to the arrangement of elements that shape these systems in a physical space (Pablo et al., 2021). Layout problems are classified into two main categories: Static Facility Layout Problem (SFLP) and Dynamic Facility Layout Problems (DFLP); in the static problem, given a group of departments, the material flow between each pair of departments, and the cost per unit of flow per unit distance with one layout plan for the whole period of the production, the departments have to be arranged into a layout such that the sum of the costs of flow between the departments in the layout is minimized. In the dynamic approach, the layout plan is based on a multi-period time horizon. During this time, if the material flow changes warrant it, layout rearrangements may be planned in one or more periods (Al-Zubaidi et al, 2021).

2.1.1. Static Facility Layout Problem (SFLP)

When the layout is planned according to the assumption that demand will remain constant throughout the planning horizon, the problem is known as the static facility layout problem (SFLP). This approach has been recommended for production systems with low rearrangement costs (Moslemipour et al, 2017). In a static layout, the material flow between machines is constant and the optimal layout is designed for a single time period. Conversely, if the layout is evaluated and modified occasionally with respect to changes in material flow, it is called dynamic layout (Tarigan et al., 2020).

2.1.2. Dynamic Facility Layout Problem (DFLP)

when a single design is contemplated, it may be impractical in most industrial sectors because it is unlikely that the materials flow remains unchanged over time. Companies need to constantly adapt to changing market needs. To do so, they increase or contract their productive capacity, change or update its technology, create new products and services, and improve or implement new processes. In this context, the need to sufficiently adopt dynamic layouts is almost mandatory. With this approach, named the dynamic facility layout problem (DFLP), an optimal layout is adopted for each period so that all the material handling costs and the facilities rearrangement costs are minimized (Al-Hawarneh et al, 2019). The factory must be able to respond quickly to changes in demand, production volume, and product mix. Dynamic layout problems take into account the possible changes in material handling flow over several periods. In this case, the planning horizon is generally divided into periods that can be defined in weeks, months, or years. The layout plan for dynamic layout problems consists of a series of layouts, each layout associated with a period (Tarigan et al., 2020).

2.2. Based on Layout Configuration/Shape

2.2.1. Single-Row Layout Problem (SRLP)

The single row layout problem (SRLP) consists of finding the most efficient arrangement of a given number of facilities or machines along one side of the material handling path, a topic that has enjoyed lasting interest for the past 45 years. As well as for use in manufacturing environments, the SRLP can serve to arrange rooms along a corridor in, e.g., hospitals and supermarkets (Keller & Buscher, 2015). Single row facility layout problem (SRFLP) is a classic problem that arranges rectangle departments, which all have the same height, in a single row to minimize the material handling cost. It is proven that this problem is an NP-hard combinatorial optimization problem (Safarzadeh & Koosha, 2017).

2.2.2. Multi-Row Layout Problem (MRLP)

Multi-row facility layout problem (MRFLP) is a class of facility layout problems, which decides upon the arrangement of facilities in some fixed numbers of rows in order to minimize material handling cost. Nowadays, according to the new layout requirements, the facility layout problems (FLPs) have many applications such as hospital layout, construction site layout planning and layout of logistics facilities. multi-row facility layout problem (MRFLP) is a generalized problem of SRFLP, so which rectangular departments must be assigned to the multi-determined rows with the same height with the aim of minimizing the sum of the center-to-center distances between all pairs of facilities. MRFLP, similar to others layout problems, has been used in different fields such as design computer and its accessories or production systems (Safarzadeh & Koosha, 2017).

2.2.3. Double-Row Layout Problem (DRLP)

The double row layout problem (DRLP) is one of the FLP layout configuration types. Work areas (or machines) are placed on the upper or lower side of a center corridor in which the material handling system is located. An automated guided vehicle (AGV) is generally used as the material handling device in this configuration and, for greater efficiency, a straight-line configuration for the AGV path is adopted (Chae & Regan, 2020). The double row layout problem (DRLP) consists of arranging rectangular facilities of different widths on both side of a corridor in order to minimize the total cost of material handling (Maadi et al, 2017).

2.2.4. Parallel-Row Layout Problem (PRLP)

Departments are arranged in two parallel rows, and the material flow of each row flows linearly and independently (Perez-Gosende et al, 2020). The objective of this problem is to order facilities in two rows with the aim of minimizing a cost function of the x-distances between facilities. PROP has a number of practical applications, including arrangement of facilities along two parallel straight lines on a floor plan and in the construction of multi-floor buildings (Maadi et al, 2017).

2.2.5. Loop Layout Problem (LLP)

Loop layout problem has been an undeniable major research trend in a facility layout problem study. Most of the resolution approaches that has been proposed is still based on a traditional approach such as an analytical- and numerical-based simulation method to obtain the best machine sequence for the manufacturing loop. The traditional approach mainly contains restrictive assumptions such as the actual distances between machines not important for the simulation which leads to the result that the final solution from the approach may not be adapted by many real manufacturing systems (Phoon et al, 2017).

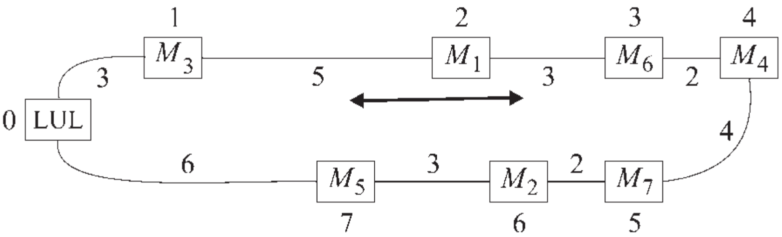

Fig. 2. Example of Loop Layout (Palubeckis, 2021).

2.2.6. Open-Field Layout Problem (OFLP)

A large class of layout problem is when the objects to be placed are represented by rectangles. The rectangles must be placed without overlap. The objective is to minimize the total transportation among the objects. The transportation quantity depends on the flow among the objects and their distances. The rectangles may represent very different kinds of things. A typical example is that the position of machines and/or cells of a factory are modeled in this way. The objective is to minimize the total transportation of the semi-finished products. A general restriction is that the rectangles must have vertical and horizontal edges and can be rotated by 90, 180, and 270 degrees. Each cell has a pick-up point which is the middle point of a fixed edge. Transportation is carried out between the pick-up points. There are four main types of layouts in this case. Open field layout does not have any further restriction. It is the most general type. Vertical and horizontal lines divide the layout into rectangular parts in the case of ladder layout. Transportation is possible on only these lines and all pick-up points must lie on the lines. If the track of the transportation is also a rectangle and the cells can be inside or outside the track then the layout is called closed loop layout. Finally, if the track is on a single line, then the name of the layout is spine (acs & ari, 2014).

2.2.7. Multi-Floor Layout Problem (MFLP)

The Multi-Floor Facility Layout Problem (MFLP) is an approach to manage limited space and budgets. The goal of MFLP is to determine the placement of facilities in a multi-floor building without any overlapping with the aim of minimizing costs. MFLP is a central problem in facility design, which can be a solution to issues like limited available space, high material handling costs, limited capacity of transportation means, air conditioning problems, traffic problems, and accessibility to facilities (Doborjeh & Koosha, 2024).

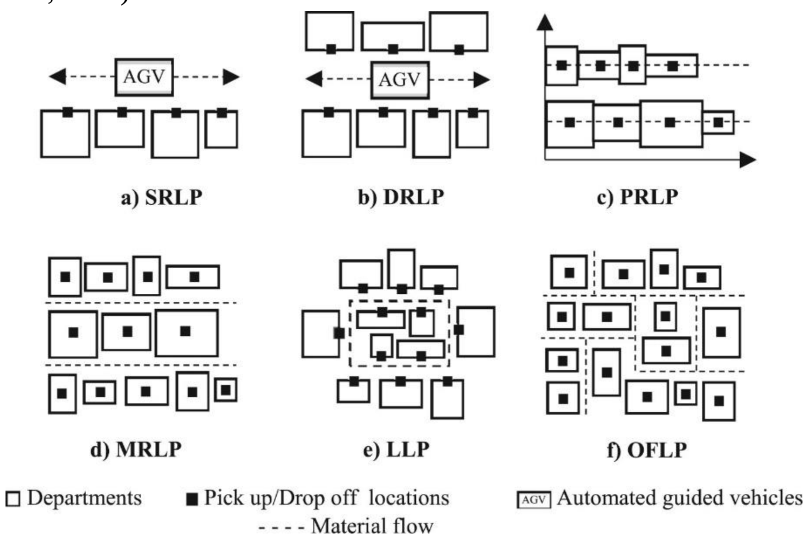

Fig. 3. Facilities Layout Based on the Material Handling System Configuration (Peres-Gosende et al., 2020).

2.3. Based on the Type of Layout Produced (Manufacturing/Service Facilities)

There are four main types of facility layout which are the following:

1) Fixed Position Layout is used in project production used for manufacturing of large and individual products e.g., bridge, ships, etc.

2) Process Layout is typically used in job shop production used for manufacturing of a low volume of customized products,

3) Cellular Layout is suitable for producing a wide variety of final products manufactured in medium volume,

4) Product Layout is used in flow shop production used for manufacturing of a high volume of standard products. In practice, the most common situation is the mixture of the above-mentioned layout types (Kovacs & Kot, 2017).

2.3.1. Product Layout (Line Layout)

The product layout is known by names such as flow-line layout, production-line layout, assembly line layout, and layout by product. In a product layout, the machines and workstations are arranged along the product route in a sequence that corresponds to the sequence of operations the product undergoes. If a product undergoes milling, drilling, assembly, and packing operations in sequence, the vertical milling machines, drilling machines, assembly equipment, and packing equipment must be arranged one after another in a line. Typically, the product layout is used by companies that manufacture a single or few items in large quantities, such as a sports utility vehicle assembly plant. Benefits of the product layout include reduced material handling time, reduced processing time, and easier planning and control. Its main disadvantage is the lack of flexibility. Once a particular product layout is adopted, the cost to make changes is significant, so a product layout is not suitable for a company that makes frequent product changes (Heragu, 2022).

2.3.2. Process Layout (Functional Layout)

The process layout concerns determining the physical location of activities in the transformation process to ensure an efficient flow of customers, materials and information through the operations system. Physical layout may not be important for information activities but is relevant in manufacturing facilities and services such as administrative activities for the design of office layouts that can facilitate teamwork among groups of people. There are four categories of process layout types: fixed position, functional, cell and line, which are placed along the volume/variety continuum. The process of grouping products or services to create a family is called group technology. The layout type choice is linked to the process type choice there may be more than one layout type which corresponds with a particular process type. In this case, the choice will depend on the characteristics of the layout type that are particularly relevant for the product or service to be delivered (Greasley,2019). Machines and workstations in a process layout are arranged based on the operations they perform. Thus, all milling machines are placed together in one department, all turning machines are placed together in another, and so on. The process layout is useful for companies that manufacture a variety of products or jobs in small quantities, where each job is usually different from any other. While the process layout offers flexibility and allows personnel to become experts in a particular process or function, it has some major disadvantages—increased material handling costs, traffic congestion, long product cycle times and queues, complexity in planning and control, and decreased productivity (Heragu, 2022).

2.3.3. Fixed-Position Layout

In a fixed-position layout, the product does not move from one location to another. Instead, the processes and equipment for making the product are brought to where the product is located. This layout is usually adopted when the manufactured or processed product is bulky and cannot be easily transported or transported at all, such as in shipbuilding and repair; aircraft manufacturing and servicing; and dam, road, and house construction industries. Automobile manufacturing companies (e.g., Nissan) that manufacture high-end models (e.g., Infiniti) also have adopted the fixed-position layout for some of their operations. Due to stringent quality and manufacturing requirements, minimal product movement is desired in some processes. The advantages of fixed-position layout are that the product, which is usually bulky and expensive, is not moved from place to place. Hence, there is lesser chance for damage to the product and the cost of moving it is reduced. On the other hand, there is a significant increase in the cost of moving equipment to and from the work area, so the utilization of equipment is low. Once the equipment is brought to the work site, it must remain there until the entire job is done. For instance, we often see bulky road-repair equipment sitting idle at a construction site. Although the equipment is used intermittently only for a few days, it must be kept at the work site until the entire road-repair job is completed (Heragu, 2022). In a fixed-position layout, the end item remains in a stationary position while it is being produced. Fixed-position layouts are common in project work where the end item is large and difficult to move (e.g., big ships, hydroelectric turbines, electrical transformers, some kinds of aircraft), and in job work where items are custom-produced by craftspeople (custom cars and machine tools). This kind of layout was used by Henry Ford and other early mass producers. At Ford, each car was assembled at one location: Materials were brought to it and workers walked around it to perform tasks (Nicholas, 2018).

2.3.4. Cellular Layout

A cellular manufacturing system consists of machine cells and part families, and each machine cell has machines or workstations. Material-handling systems such as automated guided vehicles, cranes or conveyors arc used for part transfer among machine cells. Robots or other material handlers are used for part transfer among machines in each cell. Transfer stations among machine cells are needed for part pick-up or drop-off. The cellular layout problem can be phrased as follows. A cellular design that specifies machine cells and part families is given, Information such as projected demands, transporter types and storage requirements may also be known. The problem is to determine simultaneously the relative closeness of cells, the relative closeness or machines, and the location or transfer stations for part handling, to minimize the total material flow cost (Lee, 2015).

2.4. Based on Problem Formulation (Mathematical Models)

2.4.1. Quadratic Assignment Problem (QAP)

The quadratic assignment problem (QAP), one of the most difficult problems in the NP-hard class, models many real-life problems in several areas such as facilities location, parallel and distributed computing, and combinatorial data analysis. Combinatorial optimization problems, such as the traveling salesman problem, maximal clique and graph partitioning can be formulated as a QAP (Loioa et al., 2007). A type of mathematical optimization problem that involves finding the optimal assignment of a set of objects to a set of locations, such that a quadratic objective function is minimized. The objective function typically involves the cost of assigning each object to a particular location, as well as the cost of the interactions between the objects and locations (Kusiak & Heragu, 1987).

2.4.2. Mixed-Integer Programming (MIP)

A type of mathematical optimization problem that involves both continuous and integer decision variables. In a MIP problem, some of the variables are restricted to be integer values, while others are allowed to take on any real value within a given range. A set of equality and inequality constraints are imposed on the objective function of a mixed integer programming (MIP) model, which consists of both integer and non-integer choice variables (Moslemipuer et al, 2012).

2.5. Based on Characteristics of Facilities

The facility layout problem (FLP) is one of the most important problems in production management and industrial engineering. It is a nonlinear combinatorial optimization problem defined as finding the most efficient arrangement of non-overlapping facilities on the factory floor with respect to one or more objectives subject to various constraints. Typically, the optimization goals are to maximize the utilization of the area available, minimize material-handling costs, or fulfill the adjacency or distance requirements between facilities. Furthermore, various constraints are imposed on the solution sought, such as the total area available, maximum acquisition or material handling costs, maximum maintenance costs, and other indirect expenses limits. The problem of finding the optimal layout of a set of elements occurs at various levels of a complex manufacturing environment, e.g., when arranging machines in a workshop, production lines in a production hall, or buildings on factory premises (Tompkins et al, 2010).

Numerous variants of the FLP problem have been formulated and researched. They can be categorized by different aspects as static or dynamic FLP, single- or multi-objective FLP, single- or multi-floor FLP, or FLP with equal or unequal facility areas, etc. When considering facility characteristics, several factors and design issues are addressed in the literature, such as the production variety and volume, the facility shapes and dimensions, the material handling system chosen, and different possible movement types allowed for parts, to name a few. Regarding the shapes and dimensions, there are two types of facilities: facilities with regular rectangular shapes and those with irregular shapes, i.e., generally polygons. In the former case, a facility can be defined by fixed length and width, and this facility is called fixed or rigid block. An important FLP variant with numerous practical uses is the FLP with loosely-defined facility shapes and dimensions. In that case, each facility is associated with its area and a shape constraint, e.g., the maximum aspect ratio allowed (quotient between greater and lesser side measurements) or the minimum side length (Kubalik et al, 2023).

Building on the diverse classifications of FLP, this section delves into distinct **facility characteristics** influencing layout design, which include:

- Fixed Size, Fixed Contents
- Varying Size, Fixed Contents
- Fixed Size, Varying Contents
- Rectilinear Facilities
- Irregular Shaped Facilities

2.6. Based on Optimization Objective

2.6.1. Minimizing Material Handling Cost/Distance

The objective of most facility layout problems is to minimize material handling cost, which is directly proportional to both the distance between the machines and the mix, as well as the volume of products handled. The mix and volume of products are dependent on the demand patterns, and the distance is dependent on the layout plan used for the facility. Because it is relatively difficult to change the demand patterns, and hence the mix and volume of products, the primary focus of most designers has been to deal with the distance attribute of the material handling costs (Kochhar, 2010).

2.6.2. Minimizing Production Time/Throughput Time

The main objective of facility layout design is to design more effective workflow and improve productivity of the manufacturing process by improving the flow of materials and workers between machines in the manufacturing area to minimize the total distance of goods flow, the material handling cost and the time spent in the manufacturing system. Optimum facility layout provides higher utilization of resources and cost reduction. Generally, an efficient facility layout should attempt to meet the following objectives:

● to maximize utilization of resources (space, facilities, labor force, etc.),
● to increase productivity of the company,
● to minimize material handling cost,
● to minimize the movement of goods, workers and equipment,
● to minimize overall production time,
● to minimize investments in equipment,
● to create a safe and comfortable work environment,
● to maintain the flexibility of operation (changes in the layout to introduce new products or production technology) (Kovacs, 2019).

2.6.3. Maximizing Space Utilization

operations, cost-effectiveness, and the capacity of a facility to adapt to changing production demands (Tompkins et al., 2010). Inefficient use of space can lead to cluttered work areas, increased material handling times, safety hazards, and reduced productivity (Tompkins et al., 2010). Effective layout planning focuses on organizing equipment, workstations, and storage areas in a way that minimizes unused or underutilized space while maintaining accessibility, flexibility, and safety (Muther, 1973). Vertical space utilization, modular storage systems, and compact equipment arrangements are among the strategies used to enhance spatial efficiency. Techniques such as Systematic Layout Planning (SLP) and Activity Relationship Charts, introduced by Muther (1973), provide structured methods for identifying optimal spatial configurations. Additionally, modern Computerized Layout Planning tools enable planners to simulate and analyze multiple layout alternatives to achieve better space utilization. Moreover, lean manufacturing principles emphasize eliminating non-value-adding space usage and encourage the implementation of "right-sized" layouts that support flow and minimize waste. By maximizing space utilization, organizations can reduce facility costs, delay or eliminate the need for expansion, and improve workflow efficiency. This results in increased throughput, better inventory management, and enhanced operational agility (Tompkins et al., 2010)

2.6.4. Minimizing Investment Cost

In today's highly competitive industrial environment, businesses are continually seeking ways to enhance operational efficiency and maintain a safe work environment. One of the most effective strategies to achieve both objectives is the optimization of facility layout. A well-designed facility layout plays a critical role in improving productivity, reducing costs and ensuring workplace safety. By strategically organizing the physical space in which operations take place, companies can streamline workflows, minimize inefficiencies and promote a culture of safety. Facility layout optimization involves careful planning and design of the arrangement of resources, equipment and workstations within a facility. The goal is to create a flow of materials, personnel and information that minimizes bottlenecks, waste and potential hazards, while maximizing the use of available space. This process is influenced by various factors, including the nature of the products being produced, the size and scale of operations and the need to comply with safety regulations (Jiemba, 2024).

2.6.5. Considering Ergonomics and Safety

Ensuring that facilities with hazardous operations are placed away from areas needing quiet. Arranging facilities to mitigate risks and minimize disruptive noise levels. Facility layout optimization refers to the arrangement of resources and workstations within a physical space in a way that maximizes the efficiency of operations and promotes a safe working environment. It encompasses the strategic placement of machinery, equipment, storage areas, personnel and other resources to ensure smooth workflows, reduce unnecessary movement and minimize safety risks. A well-designed layout not only helps businesses achieve higher productivity by reducing delays, bottlenecks and downtime but also enhances employee well-being by making the workspace more ergonomic and safer (Jiemba, 2024). Workplace Ergonomics the design of the layout should consider the physical demands placed on workers. Workstations should be positioned to minimize unnecessary bending, reaching, or lifting. Proper ergonomic design reduces the risk of injuries, enhances worker comfort and leads to improved productivity and job satisfaction. Ensuring that a facility is safe for employees is one of the most critical aspects of layout optimization. This involves creating clear pathways for movement, proper signage, adequate lighting and the strategic placement of safety equipment such as fire extinguishers, first-aid kits and emergency exits. Additionally, hazards such as chemical spills, machinery malfunctions, or electrical risks should be minimized through thoughtful design. Safety is an essential consideration in any facility design. Optimizing the layout can significantly reduce the risk of accidents, injuries and potential hazards. Clear Pathways and Emergency Access layout that ensures clear, unobstructed paths allows employees to move quickly and safely in emergency situations. It also ensures that emergency exits and equipment are easily accessible in case of fire, equipment failure, or other hazards (Nurazzi et al, 2020).

2.6.6. Minimizing Rework/Scrap

production efficiency, cost, and product quality. Poorly designed layouts often lead to excessive material handling, miscommunication between departments, and bottlenecks that can cause errors, defects, or damage to products. These issues increase the likelihood of rework and scrap, leading to unnecessary waste and higher operational costs. To minimize these inefficiencies, facility layout planning must emphasize logical process flows, proximity of interdependent operations, and ergonomic workstation arrangements. Lean manufacturing principles advocate for the elimination of non-value-adding activities, which include rework and scrap, by optimizing layout design. Tools such as Failure Mode and Effects Analysis (FMEA) and Process Flow Analysis can be employed during the layout planning stage to identify high-risk areas prone to defects or rework and to redesign the layout to mitigate such risks. Moreover, simulation-based layout optimization and use of multi-objective mathematical models can help evaluate different configurations and select the one that minimizes material waste, rework frequency, and production interruptions. Integration of quality control checkpoints and visual management systems within the layout can also reduce error propagation across production stages. Ultimately, a well-planned facility layout not only reduces the risk of rework and scrap but also improves overall throughput, worker morale, and customer satisfaction by ensuring a smoother, error-resistant production flow (Tompkins, 2010).

2.7. Based on Solution Approaches

Several methods or techniques are applied to design the facility layout, which is considered as the main driver (Tools and Techniques Drivers). The most widely employed techniques for facility design is Systematic Layout Planning (SLP) as an exact, heuristic, meta-heuristic, and evolutionary approach. Other techniques used for solving these problems are CRAFT, ALDEP, and CORELAP, etc. These techniques are manipulated to formulate a new facility layout.

2.7.1. Exact Methods

Exact methods, also known as deterministic methods, are algorithms or techniques that are guaranteed to produce a correct solution to a problem within a finite amount of time. For small-scale FLPs, exact methods are efficient approaches to finding optimal solutions. Unfortunately, they require a long time to achieve a goal and cannot deal with big size problems (Bouramtane et al, 2024).

2.7.2. Metaheuristic Algorithms

These work by iteratively improving a solution to a problem, using techniques such as local search, global search, or a combination of both. They often involve some form of randomization or stochasticity, which allows them to explore different parts of the search space and avoid getting stuck in local minima or maxima. They belong to a brand-new group of approximation strategies that instruct traditional construction and improvement techniques to steer clear of local optimums when doing their search. Some common examples of meta-heuristic algorithms include genetic algorithms, simulated annealing, particle swarm optimization, ant colony optimization, and tabu search.

2.7.3. Hybrid Approaches

In recent years, hybrid approaches have gained significant attention in addressing complex Facility Layout Problems (FLPs). These methods are designed to combine the strengths of different solution techniques—such as exact methods, heuristics, and metaheuristics—while mitigating their individual limitations. The primary objective of hybridization is to achieve a balance between exploration (global search) and exploitation (local search) within the solution space, thereby improving convergence speed and solution quality. Hybrid approaches often integrate metaheuristic algorithms with local search techniques or exact methods to refine solutions iteratively. For instance, a genetic algorithm might be used in the initial phase to explore the search space broadly, followed by a simulated annealing or tabu search procedure to fine-tune the obtained solutions. This combination allows for escaping local optima while ensuring precision in the final results. Moreover, some hybrid models incorporate data-driven techniques, such as machine learning or fuzzy logic, to better handle uncertainty in material flow patterns, dynamic demand fluctuations, or ergonomic considerations. These intelligent frameworks enhance decision-making capabilities by adapting to real-time changes and incorporating expert knowledge into the optimization process. One of the key advantages of hybrid approaches is their applicability to large-scale and multi-objective FLPs, where traditional methods either fail or become computationally prohibitive. By leveraging complementary strategies, hybrid algorithms can efficiently manage constraints related to unequal area departments, adjacency requirements, and multi-floor configurations. Additionally, they offer flexibility in handling both quantitative objectives (e.g., cost minimization) and qualitative factors (e.g., safety and ergonomics). As industries move toward more flexible and adaptive manufacturing systems, hybrid approaches are increasingly seen as a promising avenue for solving real-world facility layout problems. Their ability to merge theoretical rigor with practical relevance makes them a valuable tool in both academic research and industrial applications. Future research directions include the development of more robust hybrid frameworks that incorporate sustainability metrics, digital twin technologies, and advanced simulation tools for enhanced layout planning and validation.

Funding

The Facility Layout Problem (FLP) plays a crucial role in the design and optimization of production and service systems. A well-planned layout can significantly enhance operational efficiency by reducing material handling costs, improving workflow, and better utilizing available space. Throughout this discussion, it has become clear that FLPs are complex and multifaceted, influenced by various factors such as time horizon, layout configuration, facility characteristics, and optimization goals. Different classifications of FLP — including static vs. dynamic, single-row vs. multi-floor, and equal vs. unequal area arrangements — reflect the diversity of real-world applications and challenges. Each classification introduces its own set of constraints and decision-making criteria, making the problem even more intricate. Moreover, the choice of solution method — whether exact, heuristic, or metaheuristic — depends heavily on the scale and complexity of the problem at hand. One of the main objectives across most layout problems remains the minimization of material handling costs, although other important goals such as maximizing space utilization, minimizing production time, and ensuring worker safety have also gained increasing attention. As industries continue to evolve with new technologies and fluctuating market demands, the need for flexible and adaptive layouts becomes even more critical.

Despite significant progress in modeling and solving FLPs, many challenges remain, especially when dealing with large-scale, real-life scenarios. Hybrid approaches combining different optimization techniques show promise in addressing these complexities more effectively. Future research may focus on integrating sustainability and ergonomics into layout planning, as well as leveraging advanced simulation tools and digital twins for better decision support. In conclusion, while the Facility Layout Problem is inherently difficult due to its combinatorial nature, continuous improvements in methodologies and computational tools offer great potential for achieving more efficient and practical solutions in both manufacturing and service environments.

Conflicts of Interest

All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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