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Automated layout creation in production planning

Methodical investigation of algorithms for layout generation and optimization

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Abstract: Factory layout planning is a critical task in production engineering that requires balancing multiple objectives, spatial constraints, and evolving operational needs. Despite advances in algorithmic optimization, real-world planning remains a fragmented process in which logical structuring, geometric realization, and iterative improvement are often treated in isolation. This paper presents a structured, three-phase framework for integrated layout design, developed following a Design Science Research approach. The framework comprises logical layout planning, algorithmic generation of spatial configurations, and simulation-informed optimization, with each phase linked through defined data and decision interfaces. An extensive literature review forms the basis for identifying suitable algorithms for each phase, including rule-based planning methods, clustering and graph models, heuristic and parametric layout generation techniques, and a range of optimization strategies from exact solvers to metaheuristics and hybrid simulation-optimization models. The proposed model not only provides a systematic approach to integrating algorithmic and human contributions in layout planning but also serves as a strategic tool for both researchers and practitioners, enabling context-sensitive method selection and facilitating data-driven decision-making in dynamic production settings.

1 Introduction and Motivation

The planning and design of a factory layout is one of the most important tasks in production planning and has a significant impact on the efficiency, economy and flexibility of production systems. In addition to economic aspects, layout planning also influences the ergonomics, sustainability and scalability of a production site (Pourhassan and Raissi, 2017). Agile production landscapes, in particular, require ever more frequent adjustments and changes to the production layout, especially in brownfield and ramp-down or ramp-up scenarios in which existing factory structures have to be adapted or rebuilt (Burggräf et al., 2021). Manual layout planning is often time consuming. Algorithmic methods, on the other hand, are more efficient but often fail to take sufficient account of process requirements and human expertise. The challenge in layout design lies in the complexity and multicriteria nature of the planning process (Süße and Putz, 2021). Several conflicting objectives and constraints must be considered, including quantitative factors such as the minimization of parts in line, throughput times, and production costs, as well as qualitative criteria such as the flexibility of the layout and production and ergonomic aspects (Lanza et al., 2019). Finally, regulatory requirements must also be considered, including safety regulations, environmental regulations, and structural and technical building equipment restrictions. The path to a model as well as to an optimal layout is therefore iterative (Benfer et al., 2022). Thus, it is difficult to find an optimal layout in one go. In order to improve the process, a sophisticated combination of algorithms and optimization processes is required. This paper aims to provide an overview of possible ways to achieve such a chain of algorithms and methods based on a comprehensive literature review, and to document and critically assess these findings.

2 State of the Art and Algorithmic Foundations

2.1 Layout Planning as a Precondition for Layout Design

The design of production layouts does not start with the arrangement of physical stations, but with a logical layout planning phase, in which process sequences, product structures, and functional requirements are systematically defined. Following Vilarinho and Guimaraes (2003) layout planning involves:

- Identification of all required production processes,
- Grouping of operations into workstations or areas,
- Consideration of organizational, safety, and ergonomic constraints,
- Derivation of functional adjacency or flow matrices.

These outputs form the informational foundation for layout generation and optimization. While often treated as a preparatory task, layout planning significantly influences the solution space of downstream optimization. Lanza et al. (2019) and Schwabe et al. (2019) highlight the increasing importance of model-based and rule-based planning tools to formalize this early phase and enable downstream automation.

However, layout planning is often insufficiently integrated with algorithmic optimization, leading to misaligned objectives or infeasible starting conditions (Drira et al., 2007).

2.2 Algorithmic Approaches to Layout Optimization

Facility Layout Problems (FLPs) are widely studied as combinatorial optimization problems with the aim to optimize material flow, spatial efficiency, cost, and other performance criteria under a variety of constraints (Drira et al., 2007). A survey by Nordin and Lee (2016) provides a structured classification of the main solution strategies: *Heuristic* methods use simple construction or improvement rules to find good layouts quickly, often based on flow or closeness matrices. *Metaheuristics* (e.g., *Genetic Algorithms*, *Simulated Annealing*, *Tabu Search*, *Ant Colony Optimization*, *Particle Swarm Optimization*) offer greater flexibility and exploration capabilities, especially for large and complex layout spaces. *Hybrid methods* combine strengths from multiple approaches and are increasingly prevalent, especially in handling real-world complexities like multiple floors, unequal area constraints, and dynamic demand. These methods usually encode layouts using topological representations, such as permutation vectors or *slicing trees*, which are then used to generate layout candidates. Furthermore, *multi-objective optimization (MOO)* is increasingly common, reflecting the need to simultaneously balance multiple, often conflicting goals (Aiello et al., 2012 and Schäfer, 2025). However, challenges persist in defining objective weights, integrating qualitative criteria, and dealing with uncertainty or dynamics.

2.3 Simulation-Based Optimization and Decision Support

While many layout optimization methods are capable of generating numerically strong results, they often fail to capture the real-world performance of layouts in operation. Therefore, simulation techniques, particularly *discrete-event simulation (DES)* are used to evaluate material flow under stochastic demand, detect bottlenecks and inefficiencies or incorporate performance metrics like throughput and utilization. (Fu, 1994)

However, most simulation applications are used post hoc, to validate candidate layouts rather than to actively steer optimization. Only a few contributions (Azadivar and and Wang, 2000; Drira et al., 2007; Pourhassan and Raissi, 2017) explore simulation-integrated optimization loops, and even fewer combine simulation with human-in-the-loop adjustments or qualitative decision support.

2.4 Layout Generation

An often overlooked but practically crucial aspect of layout design is the spatial arrangement of layouts. While many optimization models operate on abstract topological relationships (e.g., “Station A should be near Station B”), real-world planning requires the placement of geometrically defined entities such as stations or devices in physical space. Spatial constraints such as safety zones, walls, columns, and accessibility must be considered. Similarly, overlaps, blocked paths, or implausible configurations must be avoided. (Bahrehmand et al., 2017)

Common techniques for geometric layout generation include slicing tree representations (Koopmans & Beckmann, 1957), grid-based floor plans (used in discrete optimization), force-driven or energy-optimizing layouts (from graph drawing), packing and bin packing heuristics, and rule-based or parametric generation models (Schwabe et al., 2019; Süße & Putz, 2021).

Despite these approaches, the integration of geometric feasibility into optimization remains limited. Layout generation is often performed as a separate step, disconnected from the actual optimization, corrected manually due to constraint violations, or based on simplified assumptions such as equal-sized rectangular areas or unlimited placement flexibility. The lack of robust, constraint-aware methods for geometric layout generation remains a key obstacle to the full automation of factory planning.

2.5 Human-Centered and Interactive Layout Planning

Several works have shown that layout design is rarely a fully automated process in practice (Behrendt et al., 2025; Nordin and Lee, 2016). Human preferences, heuristics, and organizational knowledge play an essential role in layout decisions, especially with regard to ergonomic considerations, company-specific best practices, and trade-offs that are not captured in objective functions (Naqvi et al., 2022). Current approaches are increasingly investigating interactive optimization systems that allow planners to select from multiple algorithmically generated solutions, manually adjust layouts at defined control points, and influence the optimization direction through preference learning or the setting of constraints (Meignan et al., 2015). However, these systems are still in the development phase and have shortcomings, such as a lack of standardized interfaces for expert input, unclear models for human-machine collaboration in layout optimization, and a lack of integration of simulation tools.

2.6 Identified Research Gaps

The literature shows that layout problems are considered separately at different levels. However, there is no holistic approach that starts at the production process level and leads to layout optimization via layout generation. In addition, human expert knowledge is often not integrated, which can lead to implausible or inefficient configurations, especially in the layout generation and optimization phase. To close these gaps, the presented framework investigates automated layout generation considering geometric feasibility criteria (RQ1: Which algorithms and methods can be used to initially create production layouts starting from production processes and what constraints are necessary?) as well as structured optimization using simulation-based methods (RQ2: Which algorithms and methods are suitable for the structured optimization of a layout based on simulation?). The targeted integration of simulation models enables the validation and iterative adjustment of layouts in real time, allowing potential bottlenecks to be identified and eliminated at an early stage. By specifically addressing these aspects, the framework contributes to the creation of consistent and practical layout solutions.

3 Methodology

To address the research gaps outlined in the previous section, particularly the disjoint treatment of planning and optimization, the insufficient integration of geometric layout generation, and the underutilization of simulation and human interaction, this study proposes a structured, three-phase methodology for automated and adaptive layout planning in production systems. The approach developed is divided into three phases that build on each other: layout planning, layout generation, and layout optimization. This structure enables the functional decoupling of the methodological requirements of each phase while ensuring a coherent overall process with iterative feedback options. The approach is based on a conceptual synthesis of the systematic analysis of existing algorithms, design-oriented approaches to production planning, and practical experience from real factory planning projects. Each phase focuses on distinct tasks, methods, and data flows, while allowing for feedback loops between phases. The conceptual structure is illustrated in Figure 1.

In line with a Design Science Research approach, we see this framework as an artefact that is based on a solid theoretical foundation but at the same time as a design concept whose practical feasibility can be investigated in later studies. This conceptual framework does not claim to prescribe all the details of implementation, but rather serves as a methodological guide that can be used in future work as a basis for prototype development, empirical validation and practical further development.

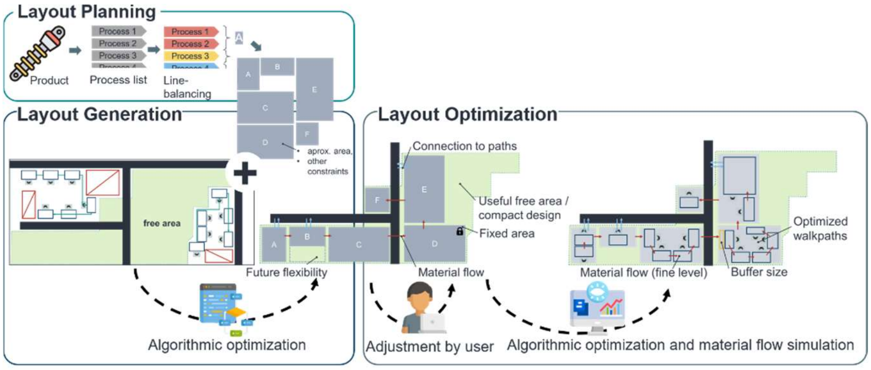

***Figure 1** Three-step layout including layout planning, generation and optimization with respect to human interaction*

3.1 Layout planning

The starting point is the systematic recording and structuring of product-specific process requirements. It is necessary to start optimizing as early as the process and station clustering stage, as these decisions will have a significant impact on the final layout in terms of the size and number of stations (Schäfer, 2025). Based on parts lists, work plans or value stream analyses, the relevant manufacturing and assembly processes are identified and transferred to a consolidated process list. These processes are then grouped functionally into workstations or areas. Technological dependencies, material flow relationships, ergonomic requirements and operational constraints are incorporated into the structuring process. This information forms the basis for the algorithmic generation of initial layout proposals. The explicit focus on a clear separation and formally traceable transfer between layout planning and generation addresses the lack of clarity at this interface, which is often criticized in the literature.

3.2 Layout generation

In the second phase, an initial geometrically valid layout design is generated based on the requirements defined in the planning phase. Unlike in optimization, the focus here is not on maximizing performance, but on designing a feasible initial configuration that serves as the basis for subsequent improvement processes. Different methods are used depending on the type of problem: grid-based models are suitable for uniform, modular layouts, while slicing tree approaches or pack heuristic methods can be used for more complex requirements. Rule-based placement patterns as in U- or L-shaped line layouts, can also be integrated into this phase. Especially in brownfield scenarios, it is important to take fixed objects (e.g., columns, existing fixtures) into account.

During layout generation, an initial consistency check is already performed with regard to space availability, overlap avoidance and basic accessibility. Any manual adjustments that may be necessary, like to correct restrictions that cannot be met are part of an interactive process. This bridges the gap between algorithmic pre-structuring and planning validation, which has not been systematically modelled in many previous works.

3.3 Layout optimization

The initial solution generated in the second phase is systematically optimized in the third phase. Established metaheuristic methods are used here, such as genetic algorithms, simulated annealing or particle swarm optimization. The aim is to improve the geometric arrangement of the stations with regard to defined target variables such as material flow costs, space utilization or ergonomic criteria. A key feature of the approach developed is the integration of simulative feedback into the optimization loop. While in many previous studies, simulation has only been used for downstream validation, here it is actively integrated into the optimization process. Each generated layout variant is subjected to a material flow simulation. The simulation's results, such as throughput times, route optimization, and buffer behavior, are directly incorporated into the evaluation and selection process. This significantly improves the accuracy of the target variables and allows for a more realistic assessment of the layout quality. At the same time, specific interaction points for human intervention are provided. This allows planners to select from a range of algorithmically generated variants, make minor adjustments or reprioritize the target weights. This human-machine interaction not only ensures greater acceptance of the solutions, but also allows the integration of decision-making criteria that cannot be formally described, such as experience, factory standards or design preferences.

3.4 Consolidation and methodological justification

The three-phase approach developed considers the different methodological requirements along the layout planning process. The separation between structuring planning, initial generation and iterative optimization allows for modular implementation and facilitates the integration of existing software tools and data sources. At the same time, explicit consideration of geometric feasibility and simulation feedback ensures that the layouts generated are not only optimal in terms of calculations, but also suitable for operational use. In addition, the interaction options provided for planners make a key contribution to bridging the gap between automated optimization and practical applicability. The approach is suitable for both greenfield and brownfield scenarios and allows for iterative further development of the layout over time, for example, in the context of dynamic production requirements, ramp-up phases or reorganization projects.

4 Algorithmic Portfolio

In the following chapter, suitable algorithmic procedures will be assigned to the three identified layout planning phases and the corresponding areas of application. The three-part framework and the method toolbox consisting of algorithms are intended to serve as a basis for decision-making for future users and further research. An overview of the investigated algorithms to the corresponding phases of layout development and their application areas can be seen in Figure 2.

4.1 Algorithmic Portfolio for Layout Planning

The methods for clustering stations and optimizing line balancing can be divided into heuristic, optimization-based, classic, and data-based approaches. Heuristic methods such as the *Kilbridge-Wester* method, *Ranked Positional Weight (RPW)*, and

COMSOAL are characterized by their ease of use and low computational intensity, making them particularly suitable for use with manageable, less complex line structures (Çelik and Arslankaya, 2023). However, these methods do not necessarily lead to optimal solutions, as they are mostly based on simplified rules and heuristics. In contrast, optimization-based methods such as branch and bound, mixed integer linear programming (MILP), and genetic algorithms are based on mathematical models that enable a systematic search for optimal allocations (Schäfer et al., 2023). These methods are particularly advantageous for complex, multi-level line structures, but require high computing power and detailed data bases. Classic methods such as the Simple Assembly Line Balancing Problem (SALBP) primarily aim to minimize cycle time or the number of stations and are suitable for static, linear production systems, while cost-oriented approaches such as CALBP also take cost aspects into account (Álvarez-Miranda et al., 2023). Data-based methods such as cluster analysis and machine learning enable flexible and data-driven grouping of stations by identifying patterns and correlations. These methods are particularly suitable for responding adaptively to changing requirements in dynamic production environments, but require extensive data sets and an appropriate infrastructure for data processing. The choice of method therefore depends largely on the complexity of the production system, the available data, and the desired target values, with simple, heuristic methods being preferred for smaller systems and data- or optimization-based methods for more complex structures.

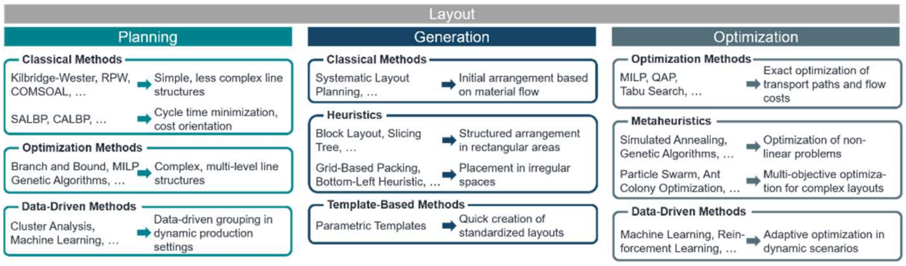

Figure 2 *Assignment of the investigated algorithms to the corresponding phases of layout development and their application areas*

4.2 Algorithmic Portfolio for Layout Generation

After clustering and summarizing the processes into stations, the second phase involves layout generation, in which the stations are initially positioned in the production area. The aim is to create an initial arrangement that takes into account the material flow and meets initial requirements for transport routes, space utilization, and ergonomics. Various methods are used for this purpose.

A basic approach is *Systematic Layout Planning (SLP)*, in which a rough layout is created based on proximity relationships between stations, which in particular clarifies the material flow connections (Abotaleb et al., 2016). In addition, *block layout methods* offer the possibility of dividing the area into clearly defined zones, which is particularly useful for rectangular hall structures (Malmborg, 2007). *Slicing tree algorithms* recursively divide the space into rectangular subareas, enabling a structured arrangement that can be easily combined with *genetic algorithms*. For existing buildings or irregular spaces, *grid-based packing methods* are a good option, as they divide the space into grids and place stations like puzzle pieces. A simpler but less efficient method is the bottom-left heuristic, which arranges stations iteratively from the bottom left to the top right. In addition, parametric layout templates enable the quick creation of standard layouts (L-shaped, U-shaped, linear) and thus provide a basis for validating initial material flow concepts.

4.3 Algorithmic Portfolio for Layout Optimization

The third phase, layout optimization, takes the initial arrangement and refines it specifically in terms of material flow, space utilization, and operational efficiency. This involves classic optimization methods such as *mixed integer linear programming (MILP)* and *quadratic assignment problem (QAP)*, which use mathematical modeling to minimize transport routes and flow costs in particular. These methods are suitable when target functions and restrictions are precisely defined and the data situation is stable (Nordin and Lee, 2016). For more complex, non-linear problems, metaheuristic algorithms are used. *Simulated annealing (SA)* enables local optima to be circumvented through controlled random modifications, while *genetic algorithms (GA)* generate iteratively improved layouts through crossover and mutation. *Particle swarm optimization (PSO)* uses swarm behavior to simultaneously optimize multiple criteria, such as material flow and space utilization. *Ant colony optimization (ACO*) is based on ant trails to identify optimal routes for transport paths. The spectrum is complemented by *tabu search (TS)*, which excludes layouts that have already been investigated in order to avoid local optima. (Azadivar and and Wang, 2000; Pérez-Gosende et al., 2021)

For dynamic layouts with changing requirements, data-based methods such as *machine learning (ML)* and *reinforcement learning (RL)* offer adaptive solutions that learn through continuous feedback and make layout adjustments (Klar et al., 2021). Hybrid approaches combine *MILP* for coarse optimization and *GA* or *SA* for fine-tuning to ensure mathematical precision on the one hand and algorithmic flexibility on the other.

5 Discussion and Outlook

The suggested framework enhances spatial arrangement by dividing the process into three sequential steps: logical planning, spatial generation, and iterative optimization. This arrangement promotes the use of specific algorithms within each step while maintaining overall coherence and control for the planners. The simulation feedback provided can be integrated into optimization loops, which allows for dynamic behavior that is often hard to model in traditional approaches.

To address complexity and flexibility increases, the framework needs to enable adaptive algorithm application. This should feature early planning rule-based logic, spatial layout generative methods with graph-based techniques, and optimization simulations with metaheuristics. Algorithms can be executed either sequentially, in parallel, or through hybrid approaches that leverage multiple methods. Decisions concerning algorithm change should be supported by data quality and temporal restrictions alongside planning objectives, possibly aided by meta-level planning frameworks.

Future work should focus on prototyping algorithm libraries, developing interface modules to CAD, ERP, and simulation platforms, and building tools for rule-based knowledge capture and interactive analytics. Empirical studies are needed to test how algorithm combinations perform in real-world scenarios and how user input, system feedback, and computational performance can be balanced. Over time, the framework could evolve into a learning system that adapts its planning strategies based on historical outcomes and user preferences.

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