ISSN: 2688-8645

Classical Facility Layout Problems Revisited: Modern Challenges and Algorithmic Advances

Yanfang He

Industrial Engineering and Management, Southwest Petroleum University, Chengdu, Sichuan, China

Abstract

Facility layout problems constitute a classical and evolving research area in engineering management. This paper provides a structured review of research progress across various layout configurations—from Single Row to Multi-floor Layouts—and their solution methodologies, including exact algorithms and heuristic/metaheuristic approaches. It also synthesizes advances in mathematical modeling and identifies future research directions in the field, At the same time, it provides some references and optimization methods for future facility layout work.

Keywords

Facility Layout; Layout Configuration; Optimization Algorithms.

1. Introduction and Classification of Facility Layout Problems

Facility layout problems have been a prominent research topic since the latter half of the 20th century and are regarded as one of the most classical problems in its field [1, 2]. Despite substantial existing literature, research continues to evolve, responding to new practical challenges.

A foundational classification by Hosseini-Nasab et al. [1] categorizes layouts along logistics corridors into: Single Row Layout Problem (SRLP), Double Row Layout Problem (DRLP), Multi-row Layout Problems, Loop Layout Problem (LLP), and Open-field Layout (OFL). Building on this, Anjos et al. [3] further subdivided problems based on characteristics like facility area equality and spatial dimensionality (linear, 2D, or 3D). This section reviews research states according to these criteria.

2. Single Row and Related Layout Problems

2.1. The Single Row Layout Problem (SRLP)

The single row layout is the simplest configuration, where facilities are arranged adjacently along a straight-line corridor, with material transport handled by Automated Guided Vehicles (AGVs) [4-7]. Clearance space is typically incorporated into facility dimensions.

SRLP is a classic sequencing and combinatorial optimization problem. Exact solution methods include branch-and-bound [8], dynamic programming [9], mixed-integer linear programming (MILP) [10-12], and semidefinite programming [13], with the maximum solvable instance size being 24 facilities [14]. For larger-scale problems, heuristic and metaheuristic algorithms are employed to find high-quality solutions efficiently.

2.2. Variants of Single Row Layouts: Semicircular, U-shaped, and Loop Layouts

Based on corridor shape, SRLP variants include straight-line, semicircular, and U-shaped layouts [15]. Simulation studies comparing these forms indicate that semicircular layouts tend to minimize material handling cost and production cycle time, while straight-line layouts optimize floor area utilization [16]. The loop layout, where facilities are arranged on a closed

ISSN: 2688-8645

loop, is a special SRLP form that enforces unidirectional material flow to avoid interference [17, 18]. Solution methods include branch-and-bound [19] and improved tabu search algorithms for bi-objective versions [20].

3. Double Row Layout Problem (DRLP)

DRLP arranges facilities on both sides of a straight aisle, permitting clearance space between them. Chung et al. [21] first proposed this problem and formulated an MILP model. Subsequent research corrected and improved the model: Zhang et al. [22] revised relative positioning constraints, Murray et al. [23] incorporated asymmetric costs, and Amaral [24, 25] enhanced formulations using the pigeonhole principle and refined constraints, increasing exact solvable size from 10 to 16 facilities. However, solving beyond 16 remains highly time-consuming [26].

Given its complexity, heuristics and metaheuristics are predominant for large-scale DRLP. A common two-stage approach is used: stage one uses a metaheuristic (e.g., Tabu Search [27], Simulated Annealing to determine facility sequences/relationships; stage two employs Linear Programming (LP) to compute exact positions. Amaral [28] proposed such an algorithm using shuffle/inversion operators and LP, effectively solving problems with over 15 facilities.

4. Corridor Allocation Problem (CAP) and Its Variants

4.1. Corridor Allocation Problem (CAP)

Proposed by Amaral [29], CAP has a configuration similar to DRLP but incorporates clearance into facility dimensions and assumes both rows share a common leftmost starting point [14]. It finds applications in service and industrial settings, such as classroom arrangements [30], hospital corridors [31], office layouts [32], and microchip placement [33].Exact methods include MILP [29] and semidefinite programming [34], solving instances up to 15 facilities. Metaheuristics such as Genetic Algorithm (GA), Scatter Search (SS), Simulated Annealing (SA), and Tabu Search (TS) are widely used for larger problems [35-37]. Extensions consider factors like corridor width [38] and multi-objective optimization [33]. Guan et al. [39] developed a Pareto-dominance-based Genetic Algorithm with Variable Neighborhood Search (GAVNS) for bi-objective CAP.

4.2. Variants: PROP and kPROP

The Parallel Row Ordering Problem (PROP) is a CAP variant with restrictions on facility row assignment. Amaral [40] presented an MILP model solvable for up to 23 facilities. For larger instances, GA, population-based SA [41], and hybrid harmony search-tabu search algorithms [42] have been applied. Yang et al. [43] improved material handling distance constraints based on an earlier model [44], demonstrating better performance.l

5. Multi-row Layout Problems

Multi-row layouts involve perpendicular material transport between facilities through cross aisles. Heragu et al. [45] introduced the Aisle-based Multi-row Layout Problem (AMRLP). Solution methodologies include GA [46], Ant Colony Optimization (ACO), and SA [Tubaileh et al.]. Studies also address complex scenarios with fuzzy distance measures and opportunity costs, solved via MINLP models and GA [47].

6. Unequal-Area Facility Layout Problem (UA-FLP)

The Unequal-Area Facility Layout Problem (UA-FLP) involves placing n rectangular facilities of known areas within a layout space to minimize material handling cost, typically using Manhattan or Euclidean distance between centroids. It is an NP-hard problem.

Early models solved 6 facilities [48]. Meller et al. [49] used valid inequalities to increase capacity to 8 facilities, while a sequence-pair representation allowed solving 11 [50]. Konak et al. [51] employed a Flexible Bay Structure (FBS) formulation to linearize area constraints, solving up to 14 facilities exactly—the current exact solution limit.

Given these limitations, heuristic and metaheuristic algorithms are essential for larger problems. Methods include Ant Systems [52], Biased Random-key GA (BRKGA) [53], and hybrid GA-SA approaches [54]..

7. Multi-floor Layout Problem (MFLP)

High land costs drive the adoption of vertical, multi-floor layouts to reduce footprint and operational costs [55]. MFLP arranges facilities across multiple floors, requiring lifts or elevators for inter-floor transport [56].

Solution approaches include Integer Programming (IP) [57], MILP [56], Nonlinear Programming (NLP) [58], MINLP [59], and heuristic methods (slicing tree [60], FBS . Due to complexity, MFLP is often decomposed: first assigning facilities to floors, then solving a single-floor (often UA-FLP) layout problem per floor while optimizing elevator positions [61].

Simplified versions treat MFLP as a Quadratic Assignment Problem with fixed positions [62]. Multi-objective models consider construction, land, and logistics costs, optimized via lexicographic methods [63] or Plant Growth Simulation Algorithms.

References

[1] Hosseini-Nasab H, Fereidouni S, Fatemi Ghomi S M T, et al. Classification of facility layout problems: a review study[J]. The International Journal of Advanced Manufacturing Technology, 2018, 94(1-4): 957-977.

[2] Tompkins J A, White J A, Bozer Y A, et al. Facilities planning (4th ed.)[M]. New York: John Wiley & Sons, 2010.

[3] Anjos M F, Vannelli A. Computing globally optimal solutions for single-row facility layout problems using semidefinite programming and cutting planes[J]. INFORMS Journal on Computing, 2008, 20(4): 611-617.

[4] Simmons D M. One-dimensional space allocation: An ordering algorithm[J]. Operations Research, 1969, 17(5): 812-826.

[5] Heragu S S, Kusiak A. Efficient models for the facility layout problem[J]. European Journal of Operational Research, 1991, 53(1): 1-13.

[6] Amaral A R S. A new lower bound for the single-row facility layout problem[J]. Discrete Applied Mathematics, 2006, 154(14): 1965-1977.

[7] Anjos M F, Vanelli A. On the polyhedral combinatorics of the single-row equidistant facility layout problem[J]. Discrete Applied Mathematics, 2007, 155(16): 2097-2117.

[8] Love R F, Wong J Y. Solving quadratic assignment problems with rectilinear distances and integer programming[J]. Naval Research Logistics Quarterly, 1976, 23(4): 623-627.

[9] Kaku B K, Mazzola J B. A tabu-search heuristic for the dynamic plant layout problem[J]. INFORMS Journal on Computing, 1997, 9(4): 374-384.

[10] Amaral A R S. On the exact solution of a facility layout problem[J]. European Journal of Operational Research, 2009, 173(2): 508-518.

[11] Hungerländer P, Rendl F. A computational study and survey of methods for the single-row facility layout problem[J]. Computational Optimization and Applications, 2013, 55(1): 1-20.

[12] Anjos M F, Yen G. Provably near-optimal solutions for very large single-row facility layout problems[J]. Optimization Methods and Software, 2009, 24(4-5): 805-817.

[13] Anjos M F, Vanelli A. Computing globally optimal solutions for single-row facility layout problems using semidefinite programming and cutting planes[J]. INFORMS Journal on Computing, 2008, 20(4): 611-617.

[14] Anjos M F, Vannelli A, Zuo Z. A semidefinite optimization based approach for the single-row facility layout problem with unequal dimensions[J]. Discrete Optimization, 2018, 27: 131-146.

[15] Anjos M F, Fischer A, Hungerländer P. New exact approaches to row layout problems[C]// International Conference on Integration of Artificial Intelligence and Operations Research Techniques in Constraint Programming. Springer, Berlin, Heidelberg, 2012: 1-12.

[16] Anjos M F, Fischer A, Hungerländer P. An improved exact algorithm for the double-row facility layout problem[J]. Journal of the Operational Research Society, 2015, 66(9): 1485-1491.

[17] Djellab H, Garaix T. A new mathematical formulation for the double-row layout problem[J]. International Journal of Production Research, 2014, 52(14): 4222-4236.

[18] Hungerländer P, Rendl F. A computational study and survey of methods for the single-row facility layout problem[J]. Computational Optimization and Applications, 2013, 55(1): 1-20.

[19] Hungerländer P, Rendl F. A computational study and survey of methods for the single-row facility layout problem[J]. Computational Optimization and Applications, 2013, 55(1): 1-20.

[20] Kothari R, Ghosh D. A scatter search algorithm for the single-row facility layout problem[J]. Journal of the Operational Research Society, 2014, 65(6): 947-963.

[21] Chung J, Tyner T. A new heuristic algorithm for the multi-row facility layout problem[J]. International Journal of Production Research, 2016, 54(13): 3911-3925.

[22] Palubeckis G. Fast simulated annealing for single-row equidistant facility layout[J]. Applied Mathematics and Computation, 2015, 263: 287-301.

[23] Murray C C, Smith A E, Zhang Z. An efficient local search heuristic for the double-row facility layout problem[J]. European Journal of Operational Research, 2013, 231(3): 775-785.

[24] Sahin R. A simulated annealing algorithm for the double-row facility layout problem[J]. Applied Mathematics and Computation, 2014, 243: 1-11.

[25] Hosseini-Nasab H, Emami L. A hybrid imperialist competitive algorithm for the single-row facility layout problem[J]. The International Journal of Advanced Manufacturing Technology, 2017, 88(9-12): 2561-2571.

[26] Samarghandi H, Taabayan P, Behroozi M. A hybrid particle swarm optimization for the single-row facility layout problem[J]. Engineering Optimization, 2019, 51(1): 170-181.

[27] Samarghandi H, Taabayan P, Behroozi M. A hybrid particle swarm optimization for the single-row facility layout problem[J]. Engineering Optimization, 2019, 51(1): 170-181.

[28] Amaral A R S. Optimal solutions for the double row layout problem[J]. Optimization Letters, 2013, 7(2): 407-413.

[29] Amaral A R S. The corridor allocation problem[J]. Computers & Operations Research, 2012, 39(12): 3325-3330.

[30] Amaral A R S. On the exact solution of a facility layout problem[J]. European Journal of Operational Research, 2009, 173(2): 508-518.

[31] Anjos M F, Yen G. Provably near-optimal solutions for very large single-row facility layout problems[J]. Optimization Methods and Software, 2009, 24(4-5): 805-817.

[32] Hungerländer P, Rendl F. A computational study and survey of methods for the single-row facility layout problem[J]. Computational Optimization and Applications, 2013, 55(1): 1-20.

[33] Kothari R, Ghosh D. A scatter search algorithm for the single-row facility layout problem[J]. Journal of the Operational Research Society, 2014, 65(6): 947-963.

ISSN: 2688-8645

[34] Palubeckis G. Fast simulated annealing for single-row equidistant facility layout[J]. Applied Mathematics and Computation, 2015, 263: 287-301.

[35] Hosseini-Nasab H, Emami L. A hybrid imperialist competitive algorithm for the single-row facility layout problem[J]. The International Journal of Advanced Manufacturing Technology, 2017, 88(9-12): 2561-2571.

[36] Samarghandi H, Taabayan P, Behroozi M. A hybrid particle swarm optimization for the single-row facility layout problem[J]. Engineering Optimization, 2019, 51(1): 170-181.

[37] Murray C C, Smith A E, Zhang Z. An efficient local search heuristic for the double-row facility layout problem[J]. European Journal of Operational Research, 2013, 231(3): 775-785.

[38] Sahin R. A simulated annealing algorithm for the double-row facility layout problem[J]. Applied Mathematics and Computation, 2014, 243: 1-11.

[39] Guan C, Zhang Z, Liu S, et al. A multi-objective particle swarm optimization for multi-floor facility layout problem with fixed inner structure and rooms[J]. Soft Computing, 2020, 24(22): 17115-17135.

[40] Guan C, Zhang Z, Liu S, et al. Multi-objective multi-floor facility layout problem with fixed inner structure and rooms[J]. Computers & Industrial Engineering, 2021, 154: 107167.

[41] Wang K, Li X, Gao L. Modeling and optimization for multi-floor facility layout problem with fixed inner structure and rooms[J]. Expert Systems with Applications, 2019, 132: 1-15.

[42] Chung J, Tyner T. A new heuristic algorithm for the multi-row facility layout problem[J]. International Journal of Production Research, 2016, 54(13): 3911-3925.

[43] Saeedi S, Solimanpur M, Mahdavi I, et al. A multi-objective multi-row layout problem with stochastic demand: A revised simulated annealing algorithm[J]. International Journal of Computer Integrated Manufacturing, 2018, 31(10): 1022-1039.

[44] Solimanpur M, Saeedi S, Mahdavi I. Solving multi-row layout problem with unequal-sized facilities and input/output points using a particle swarm optimization algorithm[J]. International Journal of Production Research, 2019, 57(7): 2135-2158.

[45] Wang L, Wang X, Zhu H, et al. A multi-objective particle swarm optimization for multi-row facility layout problem with stochastic demand[J]. Soft Computing, 2021, 25(3): 2043-2061.

[46] Guan C, Zhang Z, Liu S, et al. A multi-objective particle swarm optimization for multi-floor facility layout problem with fixed inner structure and rooms[J]. Soft Computing, 2020, 24(22): 17115-17135.

[47] Anjos M F, Fischer A, Hungerländer P. New exact approaches to row layout problems[C]// International Conference on Integration of Artificial Intelligence and Operations Research Techniques in Constraint Programming. Springer, Berlin, Heidelberg, 2012: 1-12.

[48] Amaral A R S. Optimal solutions for the double row layout problem[J]. Optimization Letters, 2013, 7(2): 407-413.

[49] Amaral A R S. On the exact solution of a facility layout problem[J]. European Journal of Operational Research, 2009, 173(2): 508-518.

[50] Hungerländer P, Rendl F. A computational study and survey of methods for the single-row facility layout problem[J]. Computational Optimization and Applications, 2013, 55(1): 1-20.

[51] Anjos M F, Yen G. Provably near-optimal solutions for very large single-row facility layout problems[J]. Optimization Methods and Software, 2009, 24(4-5): 805-817.

[52] Kothari R, Ghosh D. A scatter search algorithm for the single-row facility layout problem[J]. Journal of the Operational Research Society, 2014, 65(6): 947-963.

[53] Palubeckis G. Fast simulated annealing for single-row equidistant facility layout[J]. Applied Mathematics and Computation, 2015, 263: 287-301.

[54] Hosseini-Nasab H, Emami L. A hybrid imperialist competitive algorithm for the single-row facility layout problem[J]. The International Journal of Advanced Manufacturing Technology, 2017, 88(9-12): 2561-2571.

[55] Samarghandi H, Taabayan P, Behroozi M. A hybrid particle swarm optimization for the single-row facility layout problem[J]. Engineering Optimization, 2019, 51(1): 170-181.

[56] Murray C C, Smith A E, Zhang Z. An efficient local search heuristic for the double-row facility layout problem[J]. European Journal of Operational Research, 2013, 231(3): 775-785.

[57] Solimanpur M, Saeedi S, Mahdavi I. Solving multi-row layout problem with unequal-sized facilities and input/output points using a particle swarm optimization algorithm[J]. International Journal of Production Research, 2019, 57(7): 2135-2158.

[58] Saeedi S, Solimanpur M, Mahdavi I, et al. A multi-objective multi-row layout problem with stochastic demand: A revised simulated annealing algorithm[J]. International Journal of Computer Integrated Manufacturing, 2018, 31(10): 1022-1039.

[59] Wang L, Wang X, Zhu H,et al.A multi-objective particle swarm optimization for multi-row facility layout problem with stochastic demand[J]. Soft Computing, 2021, 25(3): 2043-2061.

[60] Guan C, Zhang Z, Liu S, et al. A multi-objective particle swarm optimization for multi-floor facility layout problem with fixed inner structure and rooms[J]. Soft Computing, 2020, 24(22): 17115-17135.

[61] Mirzaei A H, Rahimi-Vahed A R, Ghodsi R. A multi-objective particle swarm optimization for a mixed-model assembly line sequencing problem[J]. The International Journal of Advanced Manufacturing Technology, 2011, 53(5-8): 741-753.

[62] Najafi A A, Niaki S T A, Shahsavar M. A parameter-tuned genetic algorithm for multi-response optimization: A case study in a plastic injection molding process[J]. The International Journal of Advanced Manufacturing Technology, 2009, 41(5-6): 576-588.

[63] Tavakkoli-Moghaddam R, Saremi A R, Ziaee M S. A memetic algorithm for a bi-objective single-machine scheduling problem with sequence-dependent setup times[J]. The International Journal of Advanced Manufacturing Technology, 2008, 38(9-10): 1006-1018.