PJSRR (2016) 2(3): 62-76
eISSN: 2462-2028 © Universiti Putra Malaysia Press

Pertanika Journal of Scholarly Research Reviews
http://www.pjsrr.upm.edu.my/

Heuristics and Metaheuristics Approaches for Facility Layout Problems: A Survey

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Abstract – Facility Layout Problem (FLP) is a NP-hard problem concerned with the arrangement of facilities as to minimize the distance travelled between all pairs of facilities. Many exact and approximate approaches have been proposed with an extensive applicability to deal with this problem. This paper studies the fundamentals of some well-known heuristics and metaheuristics used in solving the FLPs. It is hoped that this paper will trigger researchers for in-depth studies in FLPs looking into more specific interest such as equal or unequal FLPs.

Keywords: Combinatorial optimization, facility layout, heuristics, metaheuristics

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Introduction

Facility Layout Problem (FLP) is the placement of facilities in a plant area where it is a crucial component to organizations since they represent the largest and most expensive assets of the organization. A small change in the position of a machine in a factory can affect the flow of the materials considerably. Getting it wrong can lead to inefficiency, inflexibility, high costs and unsatisfied customers. Changing the layout can be expensive and difficult. Tompkins and White (1984) agreed that effective facilities planning could reduce the manufacturing cost by at least 10% to 30%.

In designing a layout, factors such as traffic volumes between facilities, shape and area requirements, and technological constraints of individual facilities are taken into consideration. A well designed facility layout allows the manufacturing or service system to quickly respond to changes in product and service design. Meanwhile, in the manufacturing environment context, the option for a “good” layout system is extremely important to rationalize the activities involved which are equally important to the implementation of the manufacturing system and to its daily operations. FLPs are usually viewed as an optimization problem and the best layout is designed by optimizing some measure of performances subject to a set of constraints (Cheng, Gen, and Tozawa, 1995).

Facility layout problems

For people at large, problems dealing with the layout of an area would be insignificant and unworthy for high-level researches. A poorly designed layout have been known to cause monetary losses as well as causing unnecessary delays, thus, losing precious time in the process. To design a working layout is relatively easy but to design a layout which is both effective and efficient is extremely difficult and requires tremendous amount of computational processing time.

With structural and scientific methods, FLPs can generate the best layout with regards to the following requirements: machines dimension, process flow, minimum lot travelling distance, ease of work-in-process (WIP) management, minimum moving cost for machines/process, lift capacity, and also human decision such as reserved space and safety issue. The flow of the FLPs is depicted in Figure 1 and the basic mathematical model that is commonly used is as follows:

$$\min \quad z = \sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij} d_{ij} \qquad (1)$$

$$\text{s.t.} \quad \sum_{i=1}^{n} \sum_{j=1}^{n} x_{ij} = 1 \qquad (2)$$

$$\sum_{j=1}^{n} \sum_{x=1}^{n} x_{ij} = 1 \qquad (3)$$

$$x_{ij} = \{0,1\},$$

where,
n = number of facilities in the layout,
f_{ij} = flow cost from facility i to j,
d_{ij} = distance from location i to j,

$$x_{ij} = \begin{cases} 1 & \text{, if facility } i \text{ is assigned to location } j \\ 0 & \text{, otherwise} \end{cases}.$$

The layout goals are usually formulated as objective functions (1) and it is used to minimize the sum of product between flows and distances. Various constraints are necessary, for example, constraint (2) ensures that exactly one facility is assigned to each location and constraint (3) ensures that exactly one location is assigned to each facility.

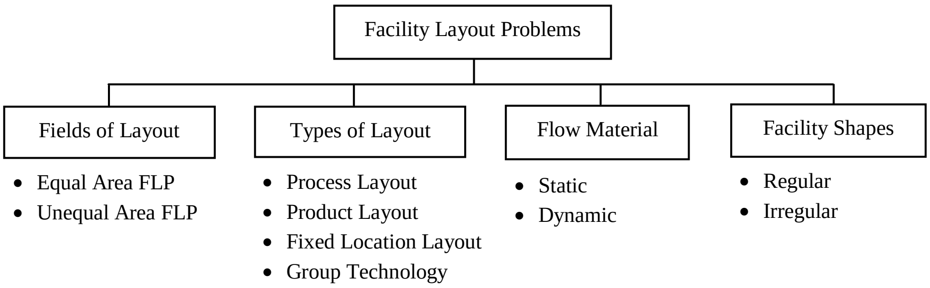

Figure 1: Facility Layout Problems.

Fields of layout
There are two fields of FLPs: equal and unequal sized FLPs. Figures 2 and 3 show the examples of equal and unequal FLPs respectively.

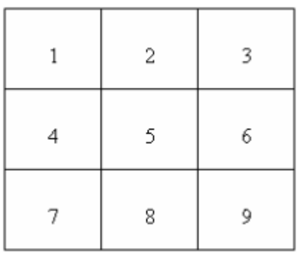

Figure 2: A layout with equal size departments.

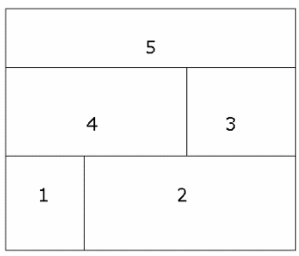

Figure 3: A layout with unequal size departments.

Equal area FLPs
If all departments are equal areas, or physically interchanged without altering the overall adjacency or distance relationships among the remaining departments, it is easy to specify in advance a finite number of potential sites for these departments to occupy. Koopmans and Beckmann (1957) are the first to model the Equal Area FLP (EA-FLP) as a Quadratic Assignment Problem (QAP). Since then, many researchers like Bazaraa (1975), Burkard and Stratman (1978), Kusiak and Heragu (1987), and Francis, McGinnis, and White (1992) have addressed the importance of QAPs and their relevance to

the EA-FLPs. Comprehensive reviews are provided in Meller and Gau (1996), Singh and Sharma (2006), Drira (2007), Pierreval, and Gabouj (2007).

Unequal area FLPs
In the real environments, departments are normally having unequal areas. Armour and Buffa (1963) proposed the Unequal Area FLP (UA-FLP) and applied a pair-wise exchange method to solve the problem without any shape constraints. Many researchers have attempted to deal with UA-FLPs like Tam (1992a), Tam (1992b), Tate and Smith (1995), Kochhar and Heragu (1998), Gau and Meller (1999), Wu and Appleton (2002), Balakrishnan, Cheng, and Wong (2003a), Teo and Ponnambalam (2008), Nordin, Zainuddin, Salim, and Rajeswari (2009), Komarudin (2009), Aiello, Scalia, and Enea (2012), and Hernandez, Pierreval, Moreraa, and Azofra (2013). The objective of UA-FLPs problem is to divide the region into sub-regions, of appropriate area taking into account that the sum of the sub-region area is equal to the area of global region, so as to minimize the total cost of the material flow. The shape of the region (i.e. plant layout) and the sub-regions (i.e. facilities) are regular and unequal.

Type of layout
A plant layout would fall into different types depending on the nature of the industry, which determines whether, the processes involved are simple or complex, the products are diversified, and the product type. Table 1 list the advantages and the disadvantages of the layouts.

Process layout is also known as functional layout where it is a layout that groups similar activities together in departments of work centres according to the process or function that they perform. As to the process layout, the design method commonly used is to find the appropriate solutions among alternatives based on the relation analysis between departments (Jue and Yun-Hong, 2006).

Product layout involves locating the machines and equipment so that each product follows a pre-arranged route through a series of processes. The products flow along a line of processes, which is clear, predictable and relatively easy to control. The problem consists of determining how to design a product that is both functional and aesthetically desirable to the customer. Every facility has to create an environment in which the product can come into existence with all the necessary capabilities and characteristics that it was intended to have with a minimum of expense, time, and effort (James and Alcorn, 1991). Decisions must be made very early in the facilities planning process regarding the assumptions concerning the objectives of the facility (Tompkins and White, 1984).

Fixed location layout is where the product remains fixed in the work area while the tools, machinery, workers, and other materials are brought to it until the job is completed (Asian Productivity Organization, 1971). In developing this layout, the product should be visualized as the hub of a wheel with materials and equipment arranged concentrically around the production point in their order of use and movement difficulty. Thus, in building custom yachts, for example, rivets that are used throughout construction would be placed close to or in the hull; heavy engine parts, which must travel to the hull only once, would be placed at a more distant location, and cranes would be set up close to the hull because of their constant use (Technical Note Five, 2003).

Group Technology is a manufacturing technology where similar parts are collectively identified and grouped to use the benefit of their relationship in design and in production. The similar parts are grouped to form part families. Each and every family has similar design and manufacturing qualities (Hassan, 1995).

Table 1: Advantages and disadvantages of different layout types

Layout	Advantages	Disadvantages
Process	• High mix and product flexibility • Robust against disruptions • Easy to supervise equipment • Less costly expansion	• Low utilisation of machines • Higher work-in-progress inventories • Complex flow is difficult to control
Product	• Low unit costs for high volume • Equipment can be specialized • Materials movement optimized	• Low flexibility • Not very robust against disruptions • Expansion requires a new complete line
Fixed Location	• Reduced handling and assembly of major components • Low capital investment in layout • Highly adaptable to frequent changes in product or production design • Cater to intermittent demand and variety of product types	• Mass production is not possible • Not adaptable to operations with complex and huge equipments • The least productive of the four
Group Technology	• Maximizes the output • Less lead time • Less setting time • Reduced scrap and material handling	• Difficult in grouping of sub-families • The flow analysis may be difficult • Required duplication of machine tools in separate cells

Flow material

Static FLP
The nature of the demand of products and services changes in short periods of time. The manufacturing plant needs to be highly flexible and capable to react quickly to the changing environment (Benjaafar and Sheikhzadeh, 2000). It is assumed that the flow of materials between facilities does not change during the planning horizon. According to Kochhar and Heragu (1999), the final layout design will be executed and remains unchanged for the effective lifetime of the manufacturing process. When optimizing SFLP, the facilities have to be arranged into a layout so that the sum of the costs of flow between the facilities in the layout is minimized. Therefore, SFLP optimization is very straightforward and only requires information on the flow between facilities and their distances. In general, the most common measurement for distance includes distance between input/output and distance between centroid to centroid of facilities, which could be measured either as rectilinear or Euclidean distances (Hillier and Connors, 1966).

Dynamic FLP
Several works take into account the possible changes in the production environment where the manufacturing plant is designed to enable it to adapt the plant to a changing environment (Rosenblatt, 1986; Balakrishnan, Jacobs, and Venkataramanan, 1992; Conway and Ventakaramanan, 1994; Balakrishnan, Cheng, Conway, and Lau, 2003b; Braglia, Zanoni, and Zavanella, 2003; and Dunker, Radonsb, and Westkampera, 2005). To solve this problem, the planning horizon is divided into periods with different material flow requirements, which can be weeks, months, seasons, and years. The dynamic layout is made up for the set of static layout where each period is associated to a static plant layout. In DFLP, the objectives are to allocate the facilities in the layout for each period in the planning horizon, minimizing the total material handling cost for all periods and the costs of layout rearrangements to adjust it to the production necessities of different periods.

eISSN: 2462-2028

Facility shapes and dimensions

Two different facility shapes are often distinguished: the regular shape, which, usually a rectangular facility (Kim and Kim, 2000) and the irregular shape, where, facilities are usually polygons that cover an angle of 270 degrees at the least (Lee and Kim, 2000). The facility dimensions, as described by Chwif, Barretto, and Moscato (1998), can be defined by means of - its fixed height and width dimensions, where a facility will be a fixed block layout - its area, its aspect ratio and a lower bound.

Overview of solution methods

To tackle the different types of FLPs, several specialized optimization methods have been developed and applied over the past decades. Metaheuristics such as simulated annealing (SA), genetic algorithm (GA), tabu search (TS), ant colony optimization (ACO), and particle swarm optimization (PSO) are the most commonly used optimization methods. On top of that, the hybrid heuristics and metaheuristics that combine several of these approaches show signs of performing well and hold promises for solving complicated FLPs in the future. The FLPs solution approaches are illustrated in Figure 4.

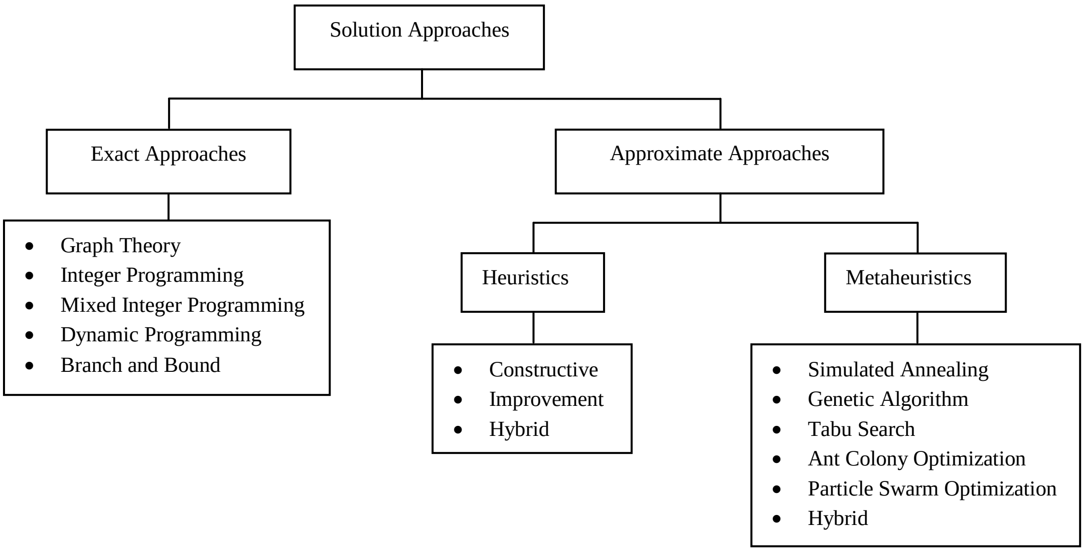

Figure 4: FLPs Solution Approaches.

Exact methods

When a problem is reasonably small or easy to solve (number of department, $n < 30$), it would be most appropriate to use exact methods that guarantee an optimal solution. There are few methods that are commonly used to solve unequal FLPs, i.e. pair-wise exchange (Fortenberry and Cox, 1985), graph theoretic approaches (Hammouche and Webster, 1985), and branch and bound (Leung, 1992). A survey of papers where these methodologies have been applied to solve FLPs is given in Table 2. Detailed research on the application of the exact methods is beyond the scope of this paper.

Table 2: Literature of exact approaches for FLPs.

Reference	Year	Methods
Foulds	1983	Graph Theory
Fortenberry and Cox	1985	Pair-wise Exchange
Hammouche and Webster	1985	Graph Theory (Theoretical Approach)
Foulds and Giffin	1985	Graph Theory
Rosenblatt	1986	Dynamic Programming
Hassan and Hogg	1987	Graph Theory
Abdou and Dutta	1990	Expert System Knowledge
Heragu and Kusiak	1990	Cut Approach
Al-Hakim	1991	Graph Theory
Leung	1992	Branch and Bound
White	1993	Knowledge Based Expert
White	1996	Branch and Bound
Zetu, Banerjee, and Schneider	1998	Maximally Plannar Graph
Knowles and Corne	2002	Extended Distance Based
Amaral	2006	Mathematical Programming
Amaral	2009	Cutting Planes Approach
Palubeckis	2012	Branch and Bound

Heuristic methods

Construction heuristics
Construction type algorithms are considered as the simplest heuristic approach, but the quality of the solution obtained did not yield satisfactory results. Seehof and Evans (1967) proposed the ALDEP method. A facility is selected randomly and it is assigned to the upper left corner of the layout. The next selected facility is the one which has a relationship that is greater than or equal to a user specified relationship, with the previous selected facility. This procedure is repeated until all facilities are allocated in the layout. Lee and Moore (1967) developed the CORELAP method which uses the total closeness rating of each facility to determine a layout. The facility with the highest total closeness rating is selected and assigned to the centre of the layout. The subsequent facilities are added to the layout depending on their relationships with the assigned facilities.

Edwards, Gillet, and Hale, (1970) proposed the MAT approach. This approach ranks pairs of facilities according to their flow values and location pairs according to their distance values. It allows the user to assign facilities to any desired location in a layout. PLANET is an algorithm that assigns the facilities in three stages that proposed by Deisenroth and Apple (1972). First, the cost of unit flows between each pair of facilities is determined. Then, the facility order is selected and finally, the facilities are placed in the layout in the order in which they have been selected in the second stage.

Zoller and Adendorff (1972) developed the LSP approach. The algorithm consists of a simulator which generates sequences in which facilities are to be allocated in a layout, and a construction mode which determines a two dimensional layout for the sequence generated previously. Tompkins and Reed (1976) formulated COFAD approach as a modification of CRAFT that includes move costs for all alternative material handling systems in the layout problem. Shore and Tompkins (1980) later modified the COFAD to incorporate flexibility in the design process and it was called COFAD-F.

Hassan, Hogg, and Smith (1986) introduced the SHAPE algorithm that uses a discrete representation and an objective based on rectilinear distance between facility centroids. The facility selection is dependent on a ranking, which is based on each facility flow and a user-defined critical flow value. The facility shape is controlled by the objective function. Camp, Carter, and Vannelli, (1991) developed the NLT algorithm based on nonlinear programming and used Euclidean distance as the distance metric. There are three sets of constrains in NLT algorithm. Authors transformed this constrained model to an unconstrained one by using the exterior point quadratic penalty function method. With a three-stage approach, more difficult problems were successfully solved using the solution from the previous stage as an initial solution point.

Improvement heuristics

Improvement type algorithms realize iterations in order to improve the initial solution. CRAFT (Armour and Buffa, 1963) is the oldest improvement-type approach. It begins by determining the centroid of each facility then performs either the two-way or three-way exchanges of the centroids of non-fixed facilities that are also equal in the area or adjacent in the current layout. CRAFT calculates and estimated the reduction in cost where it chooses the exchange with the largest estimated reduction. It exchanges the facilities and continues until there is no estimated reduction due to two-way or three-way exchanges. Hillier (1963) developed the H63 based on a move desirability table that consists of values which represent the cost changes that would result by moving a facility from its current location to an adjacent one. H63 considered only pairwise exchanges between adjacent facilities, which have equal areas.

Khalil (1973) implemented the FRAT method that uses the principles from other well-known algorithms like CRAFT and H63. It determines the difference between the longest and the shortest distance. The algorithm carries out two procedures which are the total cost determination procedure and the exchange procedure. This algorithm can only be applied to EA-FLPs. Drezner (1980) developed the DISCON method where FLPs is modelled as a nonconvex mathematical programming problem and a two-phase algorithm called dispersion-concentration is used. In the first phase, good initial conditions are found using the Lagrange differential gradient method. The second phase involved concentrating the facilities so that these are as close as possible.

Bozer, Meller, and Erlebacher (1994) proposed MULTIPLE, a multi-floor improvement-type approach. To represent a layout, they used discrete representation. MULTIPLE extends CRAFT by applying space filling curves. This approach improved CRAFT by increasing the number of exchanges considered in each iteration where it can also restrict the irregularity of facility shapes by using an irregularity measure. However, because it uses the discrete representation, the facility shapes may not be rectangular.

Metaheuristics methods

Simulated annealing

The simulated annealing (SA) was first proposed by Kirkpatrick, Gelatt, and Vecchi (1983). This technique originates from the theory of statistical mechanics and is based on the analogy between the annealing of solids and solving the optimization problems. SA can be viewed as a variant of an iterative improvement strategy.

Burkard and Rendl (1984) used the homogeneous SA where the process remains at a temperature until a fixed number of trials have been considered before proceeding to the next temperature. The temperature is lowered according to a formula. If all the temperatures have been used, the algorithm stops. Heragu and Alfa (1992) presented an extensive experimental analysis of two SA-based algorithms, implementing them on two patterns of layout, the single-row and multi-row facility layouts. The first algorithm uses the standard SA and the second is a hybrid SA algorithm.

Hasan and Osman (1995) started to hybridise SA with TS, followed by de Alvarenga, Negreiros-Gomes, and Mestria (2000) and Vilarinho and Guimarães (2003). The hybridization of different metaheuristics has also been considered for solving the FLPs. Mahdi, Amet, and Portman (1998) proposed a hybrid approach for minimizing the material handling cost. They used a SA to solve the geometrical aspect of the problem, a GA to make decisions about the material handling system and an exact method (Hitchcock's method) to minimize the total material handling utilization cost. Mir and Imam (2001) presented a hybrid approach for a layout problem with UA-FLPs. Starting from an initial solution given by a SA, the optimal locations of facilities are determined by an analytical search technique in a multi-stage optimization process. Matai, Singh, and Mittal (2013) proposed improved-SA to cater for UA-FLPs. They have shown that the proposed algorithm can efficiently solve larger multi-objective FLPs ($n \geq 30$).

Wang, Zuo, and Zhao (2014) proposed an improved-SA to deal with double row FLP. To represent a feasible solution, a mixed coding scheme is suggested to express the sequence of facilities and the exact location of each facility. Five new operators are devised to effectively solve this problem. Qin, Xiang, Ye, and Ni (2015) introduced a combined-SA algorithm to solve multiproduct capacitated FLP, in which the outer layer sub-algorithm optimizes the facility location decision and the inner layer sub-algorithm optimizes the demand allocation based on the determined facility location decision.

Genetic algorithm
The genetic algorithm (GA) is a probabilistic search algorithm based on the mechanics of natural selection and natural genetics, proposed by Holland (1975). GA is initialised with a set of individual (called population), each representing a feasible solution to the given problem. For each generation, the fitness of each individual is measured. The fitter the individuals, the more likely they are to be selected from the population using a selection mechanism to produce offspring for the next generation via a reproduction stage (crossover and mutation). After many generations, the result is hopefully a population that is substantially fitter than the original.

The first approach of GA for FLP is introduced by Tam (1992b). A solution is represented by the post order sequence of the nodes in a slicing tree. Balakrishnan et al. (2003b) developed a hybrid GA to solve the DFLP previously tackled by Rosenblatt (1986). The initial population is generated with two methods: a random method and the Urban's procedure (Urban, 1993). The crossover is based on a (Buffa, 1963) dynamic programming approach and the mutation is achieved by the CRAFT heuristic (Armour and Buffa, 1963).

Aiello et al. (2012) presented a multi-objective GA to solve the UA-FLPs. Four different aspects of the block layout problem are taken into account - handling cost, adjacency requests, distance requests and aspect ratio of departments. Hernandez et al. (2013) applied an interactive GA to address the UA-FLP that uses the decision maker expert knowledge to guide the search process, adjusting it to the user preferences at each generation and considered a large number of department, n = 20.

Gonçalves and Resende (2015) proposed a biased random key GA (BRKGA) for UA-FLP. A set of rectangular facilities with given area requirements had to be placed on a rectangular floor space. The objective is to find the location and dimension of the facilities such that the sum of the weighted distances between facilities could be minimized. A hybrid approach combining a BRKGA, to determine the order of placement and the dimensions of each facility, a novel placement strategy, to position each facility, and a linear programming model, to fine-tune the solutions, is developed. Uddin (2015) introduced a hybrid GA and variable neighborhood search (VNS) to DFLP. The proposed hybrid approach is to integrate the exploitation capacity of VNS and exploration capacity of GA and the results show that GA-VNS is mighty of attaining high quality solution.

Tabu search
The tabu search (TS) technique was developed by Glover (1986). TS, like SA, is based on the neighbourhood search with local-optima avoidance but in a rather deterministic way. The main idea is to allow climbing moves when no improving neighbouring solution exists. However, some moves are to be forbidden at present search iteration in order to avoid cycling.

Skorin-Kapov (1990) presented a TS in FLP for solving QAP. The method is implemented in a flexible manner which allows the user to interact and change the parameters, i.e. tabu list size, iteration limit, search diversification parameter and the number of new starting solutions during the implementation. Hasan and Osman (1995) developed a local search algorithms based on steepest ascent, hybrid SA and TS with a non-monotonic cooling schedule and TS with a hashing function to obtain near-optimal solutions.

Chiang and Kouvelis (1996) developed a TS algorithm with a neighbourhood based on the exchange of two locations of facilities and included a long term memory structure, a dynamic tabu list size, an intensification criteria and diversification strategies. Scholz, Petrick, and Domschke (2009) proposed a slicing tree and TS (STaTs) algorithm for solving UA-FLP. They used a slicing tree representation and incorporated a bounding curve for solving UA-FLPs and there are four types of neighbourhood moves to find better solutions.

Kothari and Ghosh (2013) presented two TS implementations. First, it involved an exhaustive search of the 2-opt neighborhood and second, it involved an exhaustive search of the insertion neighborhood. They also implemented techniques to signicantly speed up the search of the two neighborhoods. Zuo, Murray, and Smith, (2014) introduced a new approach combining multi-objective TS with linear programming for an extended double row FLPs, in which the objective is to determine the exact locations of machines in both rows to minimize material handling cost and layout area where material flows are asymmetric. A formulation of this layout problem is established at the first stage. Then, an optimization framework is proposed that utilizes multi-objective TS and linear programming to determine a set of non-dominated solutions, which includes both sequences and positions of machines. Recently, Bozorgi, Abedzadeh, and Zeinali, (2015) applied a TS algorithm using diversification strategy which includes frequency-based memory, penalty function, and dynamic tabu list size to the data envelopment analysis (DEA) model of DFLP with equal departments to obtain the most efficient layout.

Ant colony optimisation

The ant colony optimisation (ACO) was first introduced by Dorigo, Maniezzo, and Colorni (1991). It was inspired by the behaviour of ants in finding paths from the nest to the food. In the natural world, ants (initially) wander randomly, and upon finding food return to their colony while laying down pheromone trails. If other ants find such a path, they are likely not to keep travelling at random, but instead to follow the trail, returning and reinforcing it. The positive feedback eventually causes all the ants to follow a single path. The idea of the basic ACO is to mimic this behaviour with 'artificial ants' walking around the graph which represents the problem to be solved.

Gambardella, Taillard, and Dorigo (1999) is the first to apply ACO for FLPs. McKendall and Shang (2006) developed and compared three hybrids ACO for a DFLP. They combined an ACO with three local search procedures: a random descent pairwise exchange procedure, a SA, and a look-ahead/look-back procedure. Hani, Amodeo, Yalaoui, and Chen, (2007) introduced the hybrid ACO with Global Local Search (GLS) to QAP. GLS uses an augmented cost function in order to guide the local search out of a local optimum. Singh (2010) proposed a new approach of ant system embedded with 2-way local search approach named ANTELS for solving EA-FLPs. ANTELS is tested on a large set of benchmark instances taken from QAPLIB.

Chen (2013) addressed modifications to McKendall and Shang (2006) with a large number of department, n = 30, with a new data structure of DFLP solution representation. Binary and hexadecimal numbers to represent the solutions of DFLP have been used, which benefits to less memory usage. The proposed data structure for the DFLP facilitates the swapping and sorting activities when a meta-heuristic is applied. Guan and Lin (2016) introduced a hybrid variable neighbourhood search with ACO for solving the single row FLP. Three neighbourhood structures are utilized to enhance the exploitation ability and new techniques are developed to reduce the mathematical calculations of the objective function values. ACO is used as the shaking step to avoid being stuck at the local optima. On top of that, the authors proposed a novel pheromone updating rule based on the best and worst solutions of the ants. A reverse criterion based on edit distance measure is applied to help ants to converge to the best solution and reduce the solution space.

Particle Swarm Optimization

The particle swarm optimization (PSO) is a population-based method inspired by the behaviour of natural group organisms such as fishes and birds swarm. First proposed by Eberhart and Kennedy (1995), the PSO works by having a population (swarm) of candidate solutions (particles). These particles are moved around in the search space according to a few simple formulae. The movements of the particles are guided by their own best known position in the search space as well as the entire swarm's best known position. When improved positions are found, these will then come to guide the movements of the swarm. The process is repeated until an optimal solution is found.

Hardin and Usher (2005) developed a method that divides a facility into a swarm of intelligent tiles and devises a set of simple rules for tile behaviour. By using these simple rules, the tiles self-organize, and a solution to the layout problems evolves. Paul, Asokan, and Prabhakar (2006) proposed a PSO to overcome the rectangular boundary shape of most block layout solutions, having passages and inner structure walls. The problem is formulated as a constrained QAP and carries out the basic PSO algorithm, extended by a LS procedure. Rezazadeh, Ghazanfari, Mehrabad, and Sadjadi (2009) introduced an extended and improved version of the discrete particle swarm optimization (DPSO) algorithm proposed by Liao, Tseng, and Luarn, (2007) to solve DFLP for EA-FLPs. A computational study was performed with the existing heuristic algorithms, including the dynamic programming (DP), GA, SA, hybrid ant system (HAS), hybrid simulated annealing (SA-EG), hybrid genetic algorithms (NLGA and CONGA).

Ohmori, Yoshimoto, and Ogawa (2010) developed a solution to solve FLP using PSO. A novel continuous optimization approach has been designed to overcome the possibility of missing the searching opportunity caused by encoding techniques. The algorithm has shown better results for small-sized problems. Cheng and Lien (2011) exploited the artificial bee algorithm (ABA), for a constrained multi-floor FLP application. To overcome the ABA weaknesses, a hybrid PSO algorithm is implemented, where PSO’s exploration property is used to improve the solution search process. Nasab and Emami (2013) considered the problem size of $n = 40$, finding the best arrangement on the plant site of facilities based on their developed coding and decoding technique that permits one to one mapping solution in discrete space of DFLP to a PSO particle position in the continuous space. For further enhancement, the proposed PSO is hybridised with a simple and fast SA.

Chang and Lin (2013) proposed a combined algorithm, clonal selection algorithm (CSA) and ant colony system (ACS) and an immunized ant colony system (IACS) algorithm to solve UA-FLPs using a flexible bay structure representation. Four operations of CSA - clone, mutation, memory cells, and suppressor cells, are introduced in the ACS to improve the solution quality of initial ant solutions as well as to increase the differences among the ant solutions, so that the search capability of the IACO is enhanced. Zhao et al. (2014) introduced a novel improved hybrid PSO-based GA (HPSO-GA) on the basis of parallel GA. In this algorithm, chaos initialization and multi-subpopulation evolution based on improved adaptive crossover and mutation are adopted. In accordance with characteristics of different classes of subpopulations, different modes of PSO update operator are introduced. It aims at making full use of the fast convergence property of PSO. The proposed adjustable arithmetic-progression rank-based selection can prevent the algorithm from premature in the early stage and benefit accelerating convergence in the later stage.

Recently, Asl and Wong (2015) suggested a modified PSO to solve UA-FLPs with fixed departments shapes and areas throughout the time horizon. The proposed algorithm applied two local search methods and the department swapping method to improve the quality of solutions and to prevent local optima for dynamic and static problems. It also utilized the period swapping method to improve the solutions for dynamic problems.

Discussion and remarks

Since 1992, researchers started to hybridise the metaheuristics while the exact methods are still being researched and this shows that the FLPs are in diverging trend. From the literature, UA-FLP is an active and open area that encourages the authors to work with this main category of the FLPs as it can be modelled by different layout representations for future studies.

A research gap exists in multi-objective functions, detailed constraint problems, and the possible combination between exact methods, heuristics, and metaheuristic methods. This gap could be narrowed by including more relevant and realistic layout criteria. Furthermore, the PSO is the newest of all reported methods and therefore, it is not thoroughly studied, where most of the reviewed papers only provide superficial understanding into the potential of hybridizing of PSO and other metaheuristics and leaving a loophole for further research.

Overall, both exact and approximate methods for solving FLPs are still commonly used by researchers in this field. However, approximate methods for solving FLPs are gradually gaining attention from the researchers based on the quantity of work done in this field of study, especially, the metaheuristics and the hybridization methods. On the other hand, heuristic methods have experienced stagnation as more complex issues using basics heuristic methods remain unsolved due to various constraints.

Conclusion

In conclusion, the commercial software available to assist the FLPs are currently limited. Hence, there is a need to make the solution approaches more generic, enabling layout procedures in software development to support the FLPs. It can be further enhanced with the use of graphical tools to achieve a more efficient and user-friendly software through multiple graphical user-interfaces.

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