A review on implementation of meta-heuristic approaches for layout problems in dynamic business environment

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Abstract: Arrangement of the facilities on shop floor in industries termed as facility layout planning. It is a vital issue at the premature stage while designing a manufacturing structure because it affects the total manufacturing cost considerably. The dynamic environment is such an industrial condition in which flexibility exists in the demand of the product. The purpose of this research paper is to present a review on the implementation of meta-heuristics approaches for handling the problem of facility layout in a dynamic environment. Various meta-heuristic approaches which have been implemented in facility layout planning (FLP) are discussed briefly and the percent utilisation of different approaches is analysed in various time spans. Tabu search (TS), genetic algorithm (GA), particle swarm optimisation (PSO), and ant colony optimisation (ACO) are several typically used methods by researchers for layout optimisation. In the present study, % utilisation of these algorithms has been analysed for different time span, ACO utilised by maximum researchers in the time span '2010–2015'. The present study also revealed GA has been executed by most of the researchers (25%), whereas PSO (8%) utilised by very least designers.

Keywords: dynamic environment; meta-heuristic; optimisation; facility layout planning; hybrid approaches.

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1 Introduction

In the industries practically there are several problems those crop up, and due to a competitive environment, it becomes very necessary to solve them optimally. For handling a problem up-to an optimal level, it generally requires algorithms, and if meta-heuristic involved in them, such optimisation falls under meta-heuristic optimisation. Some of them are as; GA, simulated annealing (SA), differential evolution (DE), ant colony optimisation (ACO), cuckoo search, bee algorithms, firefly algorithm, PSO, tabu search (TS), harmony search etc. According to Voss (2001) almost all the available meta-heuristic algorithms are likely suitable for global optimisation. These algorithms can be applied in various fields of research in academic as well as in industries. Present study, focuses on the review of different optimisation studies for facility layout problem using meta-heuristic algorithms. The problem of facility layout is not only associated with any specific field, it also directly affects the productivity of all kinds of industries like chemical, manufacturing, electronics, construction etc.

For an industry facility layout problem deals with arranging the available facilities in such a way to get the maximum utilisation from them. These facilities on the shop floor may be machines, departments, offices etc. The selected layout guides the proper flow of material and man power within the company. An improper layout will result in reduced productivity, increased tied up capital and in some cases it can lead the personnel being exposed to unnecessary physical material handling without any due cause. Between 20% to 50% of the entire operating costs and 15% to 70% of the total cost for a product is attributed to handling of material and at least 10% to 30% of these costs could have been saved if layouts were planned effectively (Sharma and Singhal, 2015; Sharma et al., 2012). The facility layout problem can be categorised into static and dynamic; in static facility layout problem (SFLP) the material flow constant over the entire time planning horizon (Ou-Yang and Utamima, 2013), whereas in dynamic facility layout problem (DFLP), a single layout is designed for each period of multi-period planning horizon. Ulutas and Islier (2015) solved DFLP in footwear industry. Hasani et al. (2015), Kheirkhah et al. (2015), Emami and Nookabadi (2013) also considered dynamic layout problem. If the available shop floor facilities are not properly laid out, such situation leads to higher work-in-process inventory, overloading to material handling equipments, longer queues etc. For overcoming such critical situation, the layout must be designed properly and should be optimised. Such layout helps in reducing the work-in-process inventory, improves material flow and leads to better utilisation of available work space (Şahin and Türkbey, 2009; Jajodia et al., 1992). According to Tompkins et al. (2003), for getting maximum productivity from the available resources, it is very necessary to utilise them optimally; it can save 30%–70% of manufacturing cost. A survey on FLP has been carried out by Drira et al. (2007) which defines that meta-heuristic plays a very imperative role in the optimisation of the layout problems. Some meta-heuristic approaches like TS, GA, PSO, ACO, etc. are used by a lot of researchers for optimisation of layout problems (Kundu and Dan, 2012; Şahin and Türkbey, 2009; Krishnan et al., 2008). Several studies have also explored a comparative analysis of these approaches, like de Alvarenga et al. (2000) compared TS and SA in case of a single row and multi-row facility layout problems.

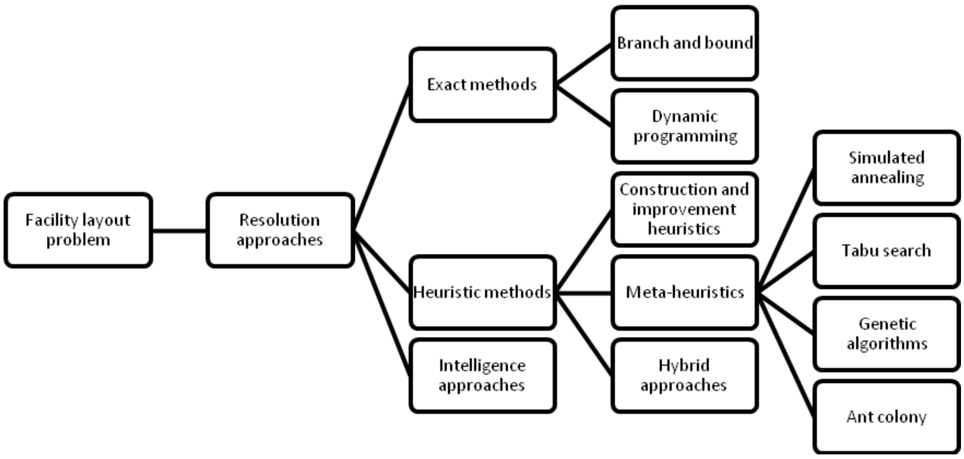
The widespread importance of layout leads to predict the future perspectives of meta-heuristic optimisation for layout planning under dynamic environmental condition and also review these for the present scenario. Reviews on meta-heuristics for facility layout have also been demonstrated by Mavridou and Pardalos (1997), which discussed a numerous applications of SA and GA. Balakrishnan and Cheng (1998) presented a survey on dynamic facility layout algorithms. The review carried out so far by various researchers, are very effective, but none of them considered the '% utilisation' of the meta-heuristics year by year, and also the analysis of up and down fall of the approaches separately year wise. In the present study, these optimisation approaches are examined on the basis of their application, and an effort is made to fulfil the above said research gap. The future trend of these considered approaches has also been predicted on the basis of mathematical charts. The paper is organised as first section represents introduction, in Section 2 briefly discussion on meta-heuristic in layout problem. Population-based search and single point search algorithms demonstrated in Sections 3 and 4 respectively. Other important meta-heuristic approaches for FLP discussed in Section 5. Future perception of meta-heuristic for FLP given in Section 6 followed by conclusions in Section 7.

2 Meta-heuristic in layout problems

Drira et al. (2007) presented 'resolution tree' for handling a layout problem, Figure 1 demonstrates it. According to them, FLP can be resolved by three approaches; exact methods, heuristic methods and with intelligent approaches. Approaches like *branch and bound algorithm* and *dynamic programming* come under exact methods. The heuristic methods can be subdivided into three approaches; *construction and improvement heuristics, Meta-heuristics* and *Hybrid approaches*. SA, TS, GAs and ACO come under meta-heuristics algorithms.

Optimisation of the layout problem using meta-heuristic are considered as *meta-heuristic optimisation*. A variety of meta-heuristic algorithms used for optimisation like cuckoo search, DE, ACO, GA, bee algorithms, firefly algorithm, particle swarm optimisation (PSO), TS, SA, harmony search etc. The meta-heuristics can be classified on the basis of their search techniques i.e., *population-based search* and s*ingle point-based search*. GA and ACO falls under population-based category and on the other hand SA and TS comes in single point search algorithm category.

Figure 1 Resolution tree for handling the layout problem



Source: Drira et al. (2007)

3 Population-based search algorithm for facility layout

3.1 Genetic algorithm

In the 1960s and 1970s, GA was developed by Holland (1992) and his collaborators. The GA is very popular and has a diverse range of applications in various fields. Crossover, recombination, mutation and selection are first used by Holland in the study of adaptive and artificial systems. Crossover, recombination, mutation and selection are four essential component of GA as a problem solution approach. The spirit of this algorithm involves the encoding of solutions as arrays of bits or character strings, the manipulation of these strings by genetic operators and a choice is based on their fitness to find a solution to a given problem. A study on hybrid multi-population GA for the DFLP is carried out by Pourvaziri and Naderi (2014). Pierreval et al. (2003) proposed an evolutionary approach to the design and organisation of manufacturing systems. Wu and Appleton (2002) optimised the block layout and aisle structure of layout using a GA. A GA for facility layout design in flexible manufacturing systems has been proposed by Rajasekharan et al. (1998). A multi-floor layout design model for dynamic cellular manufacturing system has been proposed by Kia et al. (2014). An efficient GA approach for facility layout problems has been suggested by Kothari and Ghosh (2014a). Zhang et al. (2014) applied GA in designing the functional area layout of railway logistics park. Zhang et al. (2002) considered a class of GA for multiple-level warehouse layout problems. A GA for cellular manufacturing design and layout has been suggested by Wu et al. (2007). It is observed that in the recent period GA has frequently been used by various researchers for the optimisation of the layout planning (Eklund et al., 2006; Gau and Meller, 1999; Ramkumar et al., 2009a; Wang et al., 2008a, 2880b; Delmaire et al., 1997; Kulkarni and Shanker, 2007). A biased random-key GA for the unequal area facility layout problem is studied by Gonçalves and Resende (2015). Caputo et al. (2015) demonstrated a safety-based process plant layout using GA. GA is used by Conway and Venkataramanan

(1994) for handling the DFLP by considering the budget constraint. Different problem specific customised crossover and mutation operation were developed to achieve better efficiency of GA (Delmaire et al., 1997; Wu et al., 2007; Eklund et al., 2006; Ramkumar et al., 2009b; Wang et al., 2008a; Wu and Appleton, 2002; Phanden et al., 2012a, 2012b). Conway and Venkataramanan (1994) utilised GA to solve DFLP. Balakrishnan and Cheng (2000) applied GA to solve large sized problems by using point to point cross over to expand the search space (Moslemipour et al., 2012). GA has ability to solve different kinds of combinatorial optimisation problems. It also has ability to find global best solution. It can be easily combine with other algorithms. Disadvantages of GA; it is very slow as compare to other algorithms. The crossover and mutation rates affect the convergence and stability. GA is dependent on the gene coding method. It finds sub-optimal solution.

3.2 Ant colony optimisation

ACO is based on foraging behaviour of the ants. Ants use pheromone as chemical messengers, each ant lays a scent chemical for communicating each other. All the ants are able to follow the route marked by other. When an ant found food, it marks the place with chemical and makes a route. As more and more ants track the marked route, this path becomes favoured. According to See and Wong (2008) ACO has emerged as potent meta-heuristic procedure to solve FLP. DFLP with unequal-sized facilities solved effectively by Corry and Kozan in 2004. Three different types of ACO approaches have been proposed by McKendall and Shang in 2006 to solve DFLP. ACO variant-based solution for layout problem of unequal area facilities has been considered by Komarudin and Wong (2010). Flexible bay structuring along with ACO has been used to optimise FLP by Kulturel-Konak and Konak (2011). An ACO for solving an industrial layout problem has been implemented by Hani et al. (2007). Many other researchers (Ramkumar et al., 2009b; Solimanpur et al., 2004; Teo and Ponnambalam, 2008) also focused on application of ACO in solving the facility layout problem. Marco et al. (2006) proposed different kinds of ACO algorithms such as; ant system (AS), ant colony system, elitist AS, ant-q, rank-based AS, best-worst AS, hyper-cube AS, and max-min AS. Corne et al. (1999) proposed AS to find the shortest path in the travelling salesman problem. If m is the total number of ants in the problem then, according to Marco et al. (1996) at each iteration of the algorithm, each of the $m = \sum_{i=1}^{n} b_i(t),$ ants moves from the city i at time t to city j at time $t + 1$, where $b_i(t)$ denotes the number of artificial ants in city i at time t. A cycle is the tour of each ant completed during n iterations; its time interval is equal to $(t, t + n)$, $tabu_k$ is the tabu list of the cities already been visited, it is made to prevent revisiting. Equation (1) represents the trail intensity, in this equation coefficient ρ stands for amount of trail after evaporation in the time interval $(t, t + n)$, $\tau_{ij}(t)$ represents trail intensity on edge (i, j) at time t, $\rho < 1$, the initial trial intensity $\tau_{ij}(0)$ is a small positive number. $\Delta\tau_{ij}$ can be defined as equation (2) where, $\Delta\tau_{ij}^k$ denotes the trail value, which is deposited on for each unit of length of the edge (i, j) by the ant k in the time interval $(t, t + n)$. Equation (3) gives $\Delta\tau_{ij}^k$, where L is the total tour distance, and Q is constant. Equation (4) denotes the probability of ant k moves from the current city i to nearest city j

by using the edge (i, j) with the highest trail intensity $\tau_{ij}(t)$ and visibility $\eta_{ij} = \frac{1}{d_{ij}}$, where N is the set of cities and parameters α and β indicate the significance of trail against visibility.

$$\tau_{ij}(t+n) = \rho.\tau_{ij}(t) + \Delta\tau_{ij} \tag{1}$$

$$\Delta\tau_{ij} = \sum_{k=1}^{m} \Delta\tau_{ij}^{k} \tag{2}$$

$$\Delta\tau_{ij}^{k} = \begin{cases} \dfrac{Q}{L_k} & \text{if ant } k \text{ uses edge } (i, j) \text{ in its tour in the time interval } (t,\ t+n) \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

$$P_{ij}^{k}(t) = \begin{cases} \dfrac{\left[\tau_{ij}(t)\right]^{\alpha}\left[\eta_{ij}\right]^{\beta}}{\sum_{k}\left[\tau_{ij}(t)\right]^{\alpha}\left[\eta_{ij}\right]^{\beta}} & \text{if } j, k \in \{N - tabu_k\} \\ 0 & \text{othervise} \end{cases} \tag{4}$$

This algorithm is continual till the number of tour reaches to a user defined value (Moslemipour et al., 2012). This algorithm contains robustness, flexibility and scalability in changing environment. The parameters in ACO approach initialisations at random or by trial and errors basis. The coding is difficult as compare to other approaches.

4 Single point-based search algorithm for facility layout

4.1 Simulated annealing

Kirkpatrick et al. (1983) proposed SA algorithm by generalising the metropolis's approach and replacing the atom's energy with the cost function. SA is based on metal annealing processing; the main benefit of this algorithm is its capacity to keep away from being trapped in local optima. The search moves a piecewise path; with each move probability of acceptance is evaluated. In this way, it accepts the changes that improve the objective function and also keep changes that do not improve the objective. In the field of FLP, this approach is being preferred by researchers starting from manufacturing cell design to multi-objective layout planning (Ioannou, 2007; Şahin et al., 2010; Castillo and Peters, 2003; Dong et al., 2009; McKendall et al., 2006; Şahin and Türkbey, 2009; Souilah, 1995; Sugiyono, 2006; Matsuzaki et al., 1999). Ku et al. (2011) proposed a SA-based parallel GA approach for facility layout problem. Matai (2015) solved a multi-objective facility layout problem using modified SA. Kulturel-Konak and Konak (2015) presented a large-scale hybrid SA algorithm for cyclic facility layout problems. The problems of dynamic facility layout with equal-sized facilities have been solved by Baykasoğlu and Gindy (2001). DFLP also solved with multi-start SA by Ashtiani et al. (2007). DFLP with budget constraint is handled successfully by Şahin et al. (2010). Other researchers like Mir and Imam (2001), Singh and Sharma (2008), Yang et al. (2005), and Şahin et al. (2010) also implemented SA as an optimisation tool for layout planning.

Suman and Kumar (2006), presented a survey on SA, this survey was based on single and multi-objective optimisation.

SA start with a randomly generated initial solution s^0. The algorithm has two loops, inner loop and the outer loop. At each iteration of the inner loop, a solution, s' is generated by the local search technique, in the neighbouring area of the best current solution, s. The solution s' is evaluated by the objective function f. If $f(s') \leq f(s)$ then it is accepted as a current best solution. In case of $f(s') > f(s)$ it is also accepted if $x \in (0, 1) \leq P$, where x is randomly generated number and $P = \exp((f(s) - f(s'))/T_{el}$ is the probability of accepting this non-improving neighbouring solution s.

The outer loop starts with a high a high value of a control parameter, i.e., temperature and at each iteration of this loop or at each temperature, the inner loop must be repeated until the system reaches the steady state. P is high at the initial stages of the algorithm ($P_{in} \approx 1$) and at the final stage it approach s to a very small value ($Pf \approx 0$). In the iteration el, current value of the temperature (T_{el}) of the outer loop is calculated as $T_{el} = T_0\alpha^{el}(el = 0, 1, 2,\ldots el_{\max})$, where $\alpha \in (0.80, 0.99)$ is the cooling ratio, $el_{\max}$ denotes the maximum number of the iterations of the outer loop, and T_0 denotes the initial value of the temperature, it can be calculated as $T_0 = -0.1f(s^0)/\ln(0.25)$ (Moslemipour et al., 2012). It is free of local optima. The computational time is low. SA is easy for implementation and convergent properties. The quality of solution is depends on the initial temperature and on the maximum iteration number of the inner loop.

4.2 Tabu search

Glover (1989) proposed the TS; this technique uses memory and search history as a major component of this method. Most of the available methods use the result of the last steps and these are memory less but TS is opposite to these. Due to the use of search history, TS has avoided revisiting recently tried local solutions and it saves a significant amount of computing time. TS is widely used in FLP for optimisation of material handling cost, minimisation of re-layout cost, utilisation of space, etc. (Abdinnour-Helm and Hadley, 2000; McKendall and Hakobyan, 2010; Seo et al., 2006; Scholz et al., 2009; Yang et al., 1999). An approach for handling DFLP has been presented by Kaku and Mazzola (1997). A large sized DFLP with ‘un-equal size facility’ solved by McKendall and Hakobyan (2010). Some other researchers also found the application of TS in solving the layout problem like Sugiyono (2006), Miao and Xu (2009), Kaku and Mazzola (1997), Chiang (2001) and Chang et al. (2009). Uncertainty in production volume and flexibility in the product routing is considered by Kulturel-Konak et al. (2004). TS heuristic for efficiency of DFLP has been proposed by Bozorgi et al. (2015). TS, GA, and SA are compared on different types of FLP by Arostegui et al. (2006). TS starts with an initial solution s^0 as the best current solution s (i.e., $s^0 = s = s^*$). A new solution s' is produced at each iteration, during a local search process in the neighbourhood of the current solution s. if s' is better than s, then, it is considered as the best solution (i.e., $s' = s = s^*$). In order to find optimal solution, the very soon found solutions, which are taboo and forbidden to be visited, are stored in tabu list (Moslemipour et al., 2012). The oldest number from the list must be removed for keeping the size of the tabu list constant, and it will be continued till termination criterion is fulfilled. TS use flexible memory to retain the history. The output solution is not necessarily an optimal solution.

5 Other FLP algorithms

There are some other approaches also have been applied for facility layout problems like an artificial immune system (AIS)-based algorithm to solve unequal area facility layout problem proposed by Haktanirlar Ulutas and Kulturel-Konak (2012). Scatter search (SS) algorithm for layout problem in flexible manufacturing systems suggested by Satheesh Kumar et al. (2008). This approach also implemented by Pantrigo et al. (2012). Kothari and Ghosh (2014b) suggested a SS algorithm for the single row facility layout problem. Saravanan and Arulkumar (2015) implemented artificial bee colony algorithm for design and optimise the fixed area layout problems. Ripon et al. (2013) proposed adaptive variable neighbourhood search for handling multi-objective facility layout problems with unequal area facilities. Wang and Tang (2011) presented an improved adaptive GA based on hormone modulation mechanism for job-shop scheduling problem of industries.

5.1 Particle swarm optimisation

Kennedy and Eberhard (1995) developed PSO based on swarm manners in nature. After then, this technique got lots of attention, and became the centre point of research in the field of intelligence of the swarm. PSO has been applied in various fields of research like design and scheduling problems, parameter optimisation of machine, etc. By adjusting the trajectories of individual particles, it searches the space for the objective function, and these particles trace a piecewise path which can be modelled in position vector. Particle updates its location to the new, when finds a location better than previously found and it will continue till particle finds a global best among all the current best solution after a certain number of iterations. Facility layout problem can also be solved with PSO. PSO has been applied in FLP by some researchers (Paul et al., 2006; Ohmori et al., 2010; Teo and Ponnambalam, 2008; Hardin and Usher, 2005; Durán et al., 2008; Reddy et al., 2012). Asl and Wong (2015) Solved unequal-area static and DFLPs by implementing modified PSO. According to Wang et al. (2008c) and Rezazadeh et al. (2009), in PSO, including m particles, equation (5) and equation (6) are used to update the position and velocity of the particle i at iteration t respectively. The dimensional vectors $X_i^t = (x_{i1}^t, x_{i2}^t, x_{i3}^t, \ldots, x_{id}^t)$ and $V_i^t = (v_{i1}^t, v_{i2}^t, \ldots, v_{id}^t)$ (i = 1, 2, 3,…,m) represents the position and flying velocity coordinates of the i^{th} particle at iteration t. The position coordinates of particle i associated with its *pbest* and *gbest* fitness values at iteration t are also represented by $P_i^t = (p_{i1}^t, p_{i2}^t, p_{i3}^t, \ldots p_{id}^t)$, and $P_g^t = (p_{g1}^t, p_{g2}^t, \ldots, p_{gd}^t)$ respectively.

$$v_i^t = \left(\omega v_i^{t-1} + c_1 r_1 \left(p_i^{t-1} - x_i^{t-1}\right) + c_2 r_2 \left(p_g^{t-1} - x_i^{t-1}\right)\right) \tag{5}$$

$$x_i^t = x_i^{t-1} + v_i^{t-1} \tag{6}$$

where

t iteration number

ω inertia weight

c_1, c_2 are usually equal to 2, are *cognition learning factor* and *social learning factors* respectively

r_1, r_2 random numbers uniformly distributed in [0, 1].

According to Clerc and Kennedy (2002) in order to prevent the particle's velocities grow to infinity, the suitable values of ω, c_1 and c_2 must be selected (Moslemipour et al., 2012).

5.2 Hybrid algorithm

Hybrid algorithms are made by the combination of various solution approaches. In facility layout problems, these algorithms play a very effective role in reaching an optimised solution. For solving the layout problem a combination of GA, SA and Hitchcock's method has been proposed by Mahdi et al. in 1998. SA, GA and TS, are combined in a single algorithm for handling fixed shape and unequal sized layout problem by Lee and Lee (2002). A GA-SA-based algorithm for layout design has been presented by Leno et al. (2015). A hybrid algorithm for optimising facility layout has been considered by Tasadduq et al. (2015). GA with SA is proposed by Huntley and Brown (1991) for obtaining a hybrid algorithm. A hybrid approach for handling the unequal sized facility layout is considered by Mir and Imam (2001), in their algorithm initial solution is generated by SA and for determining the optimal location of facilities analytical search is applied. The DFLP has been solved by Erel et al. (2003) using a three stage hybrid algorithm. Hasani et al. (2015) suggested a hybrid meta-heuristic for dynamic layout problems with transportation system design using variable neighbourhood search (VNS) and SA. Chen et al. (2015) combined improved adaptive GA with SS for layout problem in non-rectangular logistics parks with split lines. Hu et al. (2013) proposed a hybrid approach using the SS, improved adaptive genetic, and expectation maximisation algorithms for phase-type distribution fitting. A hybrid meta-heuristic algorithm has been suggested by Rodriguez et al. in 2006 for handling DFLP. Table 1 shows a list of meta-heuristic approaches used for handling facility layout problem.

Table 1 List of meta-heuristic approaches used for handling facility layout problem

Reference	*Year*	*GA*	*TS*	*SA*	*ACO*	*PSO*	*Hybrid*
Souilah	1995			✓			
Ashtiani et al.	2007			✓			
Asl and Wong	2015					✓	
Azadivar and Wang	2000	✓					
Balakrishnan and Cheng	2000	✓					
Balakrishnan et al.	2003						✓
Baykasoğlu and Gindy	2001			✓			
Baykasoglu et al.	2006				✓		
Castillo and Peters	2003			✓			
Chang et al.	2009		✓				
Chen and Lo	2014				✓		
Chen and Rogers	2009				✓		
Chiang	2001		✓				
Chwif et al.	1998			✓			

Table 1 List of meta-heuristic approaches used for handling facility layout problem (continued)

Reference	*Year*	*GA*	*TS*	*SA*	*ACO*	*PSO*	*Hybrid*
Conway and Venkataramanan	1994	✓					
Corry and Kozan	2004				✓		
Dong et al.	2009			✓			
Drezner	2008						✓
Dunker et al.	2005						✓
Durán et al.	2008					✓	
Engelbrecht	2005					✓	
Erel et al.	2003						✓
Ficko et al.	2004	✓					
Gau and Meller	1999	✓					
Hani et al.	2007				✓		
Hardin and Usher	2005					✓	
Abdinnour-Helm and Hadley	2000		✓				
Hicks	2004	✓					
Hu and Wang	2004	✓					
Hu et al.	2007	✓					
Huntley and Brown	1991						✓
Ioannou	2007			✓			
Jayachitra and Prasad	2010	✓					
Jeong et al.	2009						✓
Ji et al.	2006						✓
Kaku and Mazzola	1997		✓				
Kia et al.	2014	✓					
Kochhar and Heragu	1999	✓					
Komarudin and Wong	2010				✓		
Kulturel-Konak and Konak	2011				✓		
Kothari and Ghosh	2014a	✓					
Krishnan et al.	2008	✓					
Krishnan et al.	2009	✓					
Ku et al.	2011			✓			
Kulkarni and Shanker	2007	✓					
Kulturel-Konak et al.	2004		✓				
Lee and Lee	2002						✓
Li et al.	2009						✓
Liang and Chao	2008		✓				
Liu and Abraham	2007						✓
Liu and Li	2006	✓					
Longo et al.	2005	✓					

Table 1 List of meta-heuristic approaches used for handling facility layout problem (continued)

Reference	*Year*	*GA*	*TS*	*SA*	*ACO*	*PSO*	*Hybrid*
Mahdi et al.	1998						✓
Arostegui et al.	2006		✓				
Matai	2015			✓			
Matsuzaki et al.	1999			✓			
McKendall	2008		✓				
McKendall and Hakobyan	2010		✓				
McKendall and Shang	2006				✓		
McKendall et al.	2006			✓			
Miao and Xu	2009						✓
Mir and Imam	2001						✓
Ning et al.	2010				✓		
Ohmori et al.	2010					✓	
Osman et al.	2003	✓					
Paul et al.	2006					✓	
See and Wong	2008				✓		
Poli et al.	2007					✓	
Rajasekharan et al.	1998	✓					
Ramkumar and Ponnambalam	2006						✓
Ramkumar et al.	2009b				✓		
Ramkumar et al.	2009a	✓					
Reddy et al.	2012					✓	
Rezazadeh et al.	2009					✓	
Rodriguez et al.	2006						✓
Şahin and Türkbey	2009			✓			
Şahin et al.	2010			✓			
Samarghandi and Eshghi	2010		✓				
Samarghandi and Jahantigh	2011					✓	
Scholz et al.	2009		✓				
See and Wong	2008				✓		
Seo et al.	2006		✓				
Singh and Sharma	2008			✓			
Sirirat and Peerayuth	2007						✓
Smith and Norman	2000	✓					
Solimanpur et al.	2004				✓		
Solimanpur et al.	2010				✓		
Souilah	1995			✓			
Sugiyono	2006		✓				
Suman and Kumar	2006			✓			

Table 1 List of meta-heuristic approaches used for handling facility layout problem (continued)

Reference	*Year*	*GA*	*TS*	*SA*	*ACO*	*PSO*	*Hybrid*
Surya	2009		✓				
Teo and Ponnambalam	2008						✓
Thangavel et al.	2006				✓		
Tuzkaya et al.	2013						✓
Wang et al.	2008b	✓					
Wang et al.	2008a	✓					
Wu and Appleton	2002	✓					
Wu and Ji	2008	✓					
Wu et al.	2007	✓					
Yang et al.	1999		✓				
Yang et al.	2005			✓			
Zhang et al.	2014	✓					

6 Future perception of meta-heuristic for FLP

Importance of meta-heuristic optimisation in the field of facility layout planning in today's dynamic environment can be easily observed from the above discussion. Maximum researchers have been attempted PSO, GA, ACO, SA, TS, and hybrid algorithms for DFLP optimisation. These algorithms have various advantages and disadvantages; GA has ability to solve different kinds of combinatorial optimisation problems. The coding in ACO is difficult as compare to other approaches. The computational time for SA is low. ACO works on principle of minimisation behaviour, so it can be considered as the most suitable for the facility layout problems with a goal to minimise the material handling cost. But still this algorithm is in its improvement phase. Results of SA as optimisation tool are considerable, if we compare the utilisation of this approach with ACO and PSO; it is applied by a huge number of researchers. TS widely used in layout planning for optimisation of material handling cost, utilisation of space, minimisation of re-layout cost, etc. The GA applied in most of the research, it is the oldest technique and still in the eyes of researchers. PSO has been utilised by very few researchers; the outcomes of the implementation of this approach are appreciable. From the present study authors analysed the '% utilisation' of different meta-heuristic approach during different time span (such as; 'before 2000', '2000–2004', '2005–2009', '2010–2015'). It is crystal clear from this analysis that, GA and SA widely used by most of the researchers, on the other hand PSO and ACO did not utilised by any of the researchers. For the span of 'before 2000', GA and SA have been utilised by more researchers (33%). TS and hybrid algorithms were used by 17% of the researchers whereas the utilisation of ACO and PSO were almost negligible. In the next time span '2000–2004', the % utilisation of GA was 41% which was also the highest for this particular approach among different considered time spans. Hybrid approaches were utilised by 23% researchers. TS and SA were considered by 13% and 14% researchers respectively however, this % utilisation of these approaches were decreased from period 'before 2000'. ACO and PSO were at their initial level of being utilised by different researchers. For the span of '2005–2009', almost all the approaches were equally utilised and the % utilisation was varying from 11–21%. But, in '2010–2015' time span, ACO utilisation was at its boom (46%). PSO was also utilised by 15% researchers and GA was declined to 8% which was 41% in '2000–2004'. Figure 2 and 3 demonstrates the research output in the form of graph and chart form which further supports the above discussed data. If a comparison made on overall percent utilisation (Figure 4), author observed from the analysis GA used by most of the researches (25%) and PSO least utilisation (8%). Hybrid approaches (19%) stands in second place, these overcomes the weakness of some other solution approaches, by using the strength of some other technique. The present research output reveals that the older approaches i.e., GA and SA declined from past to present and it is further predicted that the improvement chances of these methods in next future are very lesser. On the other hand, approaches i.e., ACO and PSO are at their increasing phase at are predicted to be at higher in future. Some approaches were at their constant level of utilisation i.e., hybrid and TS and in near period it is also predicted that these methods will be highly utilised. The outcome of the present study will help the industrial layout designers to take decision regarding the selection of appropriate approach for layout problems. One approach never been best for all the similar kind of problems and also not best suited in all environmental conditions.

Figure 2 % utilisation vs. time period for different approaches (see online version for colours)

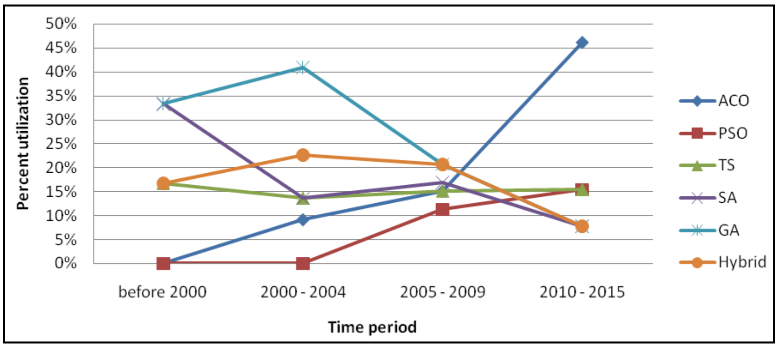


Figure 3 Comparison of percent utilisation for different approach in different time span (see online version for colours)

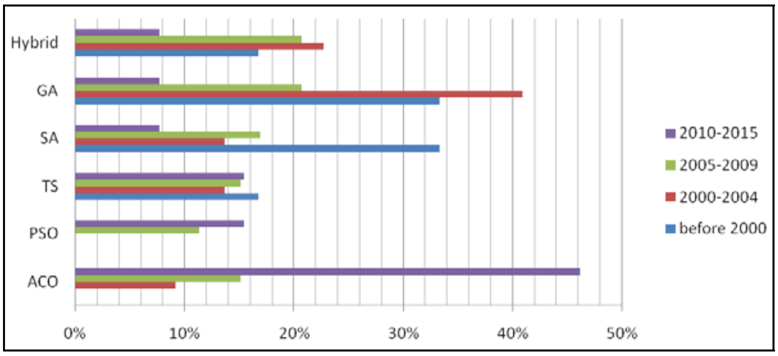
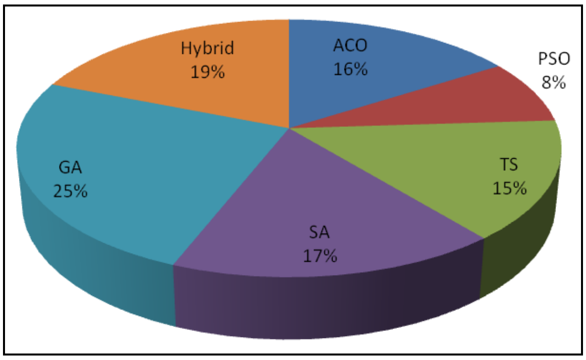


Figure 4 % utilisation of different meta-heuristic for FLP (see online version for colours)



7 Conclusions

In the present study, various meta-heuristic approaches used in the FLP are discussed briefly. Research papers based on these approaches have been categorised. The meta-heuristic approaches are classified based on their search algorithm (single point search and population-based search). From the literature, authors observed that PSO, GA, TS, and ACO are mostly used by researchers for layout planning. Comparison based on percent utilisation also has been presented in the form of figure and table which reveals that the percentage utilisation are as: GA (25%) > Hybrid approaches (19%) > SA (17%) > ACO (16%) > TS (15%) > PSO (8%). In the present study, % utilisation of these algorithms has been also analysed for different time span, in the period of 'before 2000' GA and SA were used by most of researchers, and also GA was at its best in span '2000–2004'. During '2005–2009', all the considered approaches were utilised equally. But in '2010–2015', ACO was at its highest utilisation. The prediction of the future study for these considered approaches has also been made.

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