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A Review of Meta-heuristic Approaches to Solve Facility Layout Problem

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Abstract—

In this paper an effort is made to present a state-of-the-art review of meta-heuristic approaches in solving facility layout problems. Facility layout directly affects the productivity of the industries so it is very important to solve it carefully. There are many approaches, methods and techniques to solve and optimize the layout problem. The current and future trends involving design objectives, algorithms and methodologies are presented in this paper. A trend towards multi-objective approaches using meta-heuristics such as particle swarm optimization (PSO), genetic algorithm (GA), ant colony optimization (ACO) and simulated annealing (SA) is observed. It is also observed that some facility layout software also developed using these meta-heuristics.

Keywords— meta-heuristic; facility layout problem; optimize; algorithms; genetic algorithm; etc

I. INTRODUCTION

Koopmans and Beckmann defined the facility layout problem as a common industrial problem in which the objective is to configure facilities, so as to minimize the cost of transporting materials between them [1]. Meller et al. considered that the facility layout problem consists in finding a non-overlapping planar orthogonal arrangement of 'n' rectangular facilities within a given rectangular plan site so as to minimize the distance based measure [2]. Azadivar and Wang defined that the facility layout problem as the determination of the relative locations for, and allocation of, the available space among a given number of facilities [3]. Lee and Lee reported that the facility layout problem consists in arranging 'n' unequal-area facilities of different sizes within a given total space, which can be bounded to the length or width of site area in a way to minimize the total material handling cost and slack area cost [4]. Shayan and Chittilappilly defined the facility layout problem as an optimization problem that tries to make layouts more efficient by taking into account various interactions between facilities and material handling systems while designing layouts [5].

According to Muther, Moore and Apple the main objectives are reached through the attainment of some facts like [6,7,8]: Reduce risk to health and improve safety of employees, Improve morale and worker satisfaction, Increase output, Decrease production delays, Proper floor space utilization, Reduce material handling, Better utilization of Machines, Manpower, and Services, etc.

II. FACILITY LAYOUT PROBLEM

According to Tomkins et al. and Singh et al., in 1999 companies in the United States invested about $1.04 trillion in capital goods and $297.4 billion of that was used on new buildings [9, 10] . About 8% of United States gross national product is spent on new facilities each year. The chosen layout guides the material flow through the company and is consequently fundamental for if the company is effective or not, Between 20 and 50% of the entire operating costs and 15–70% of the total cost for a product is ascribed to material handling and at least 10-30% of these costs could be saved if effective facility planning were applied [9]. A good plant layout decreases lead times, and increases the output, and consequently increases overall productivity of the plant.

III. SOLUTION METHODOLOGY

Layout problem can be defined as an optimization problem, and a mathematical model also a way to solve it. The layout objectives and the other requirements should be considered when build a mathematical model to formulate the layout problem. According to Tao et al., the mathematical model can be categories into three models [11]: Quadratic Assignment Problem (QAP), Graph Theoretic model (GT), and Mixed Integer Programming (MIP). There are some other optimization approaches also available, like traditional heuristic approaches and intelligent optimization approaches. Drira et al., Singh et al., and Tao et al. gives traditional heuristic approaches can be categorized into three kinds [11, 12, 10]: construction algorithms (CORELAP, ALDEP, COFAD and SHAPE, etc), improvement algorithms (CRAFT, FRAT, FLEX-BAY and MULTIPLE, etc) and hybrid algorithms (FLAC and DISCON, etc). Many intelligent optimization approaches are given by Benabes et al., Reddy et al., Jayahitra and Prasad include Genetic algorithm (GA), Tabu Search (TS), Simulated Annealing (SA), Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) have been developed to solve Facility Layout Problem [13,14,15].

IV. REVIEW OF LITERATURE

A facility layout planning is about arranging the physical departments or machines within a facility to help the facility work in a productive way. A poor layout can lead to accumulation of work in process inventory, overloading of material handling system, inefficient setups and longer queues.

Survey of facility layout literature done for this research is given below. The main objectives taken by the researchers are tabulated in columns *a* to *d* and detailed out as follows:

a. *Minimization of Material handling and total closeness between machines/department*
b. *Minimization of material handling cost*
c. *Minimization of Material flow*
d. *Minimizing total distance travel for material*

Table 1 Review of meta-heuristic based FLP literature with objective considered by different researcher.

Longo et al. [16] proposed the steps of the project of plant layout undertaken for a production system of wood product manufacturer. The first step of the project was an accurate analysis of the system together with the design of new production documents in order to collect data about the system itself .The collected data was used to propose an initial solution of plant layout. The second step of the project was the realization of a simulation model. The model was used to find an optimal plant-layout configuration by means of genetic algorithms with the goal of material handling cost minimization. The optimized plant layout configuration obtained was compared with the initial one, observing the behavior under the effect of different demand market levels and variability levels. The results obtain showed remarkable material handling cost decrements for the optimal solution. Liu et al. [17] discussed the facility layout problem with stochastic product demand and logistic flows. The shape of the department was fixed, but the rotation was allowed. Criteria considered in this paper included not only the traditional material handling cost but also the shape ratio factor and the operational performance such as Work In Process (WIP) value. Material handling cost was formulated by the mean value and the standard deviation. A hybrid algorithm based on tabu search and simulated annealing was constructed to solve the problem. Experimental results illustrated the effectiveness of the proposed algorithm. A ten department's problem was considered and finally the optimal solution was found. Through the computational experiments, the results showed that proposed algorithm was effective and practical for use.

Kulkarni and Shanker [18] presented a mathematical formation using genetic algorithm as solution methodology for facility layout problem. In order to validate the performance of the algorithm a well known quadratic assignment problem that deals with location were taken for testing, and that indicated promising results of proposed methodology. The effectiveness of developed approach was evaluated with numerical problems. Problem 1: five machines were to be assigned to five locations, Problem 2: To determine the frequency of the trips between each pair of cell, Problem 3: The performance of developed algorithm was evaluated through comparison with other heuristics. The proposed method obtained the optimal solution for the problem selected. Problem 1 obtained the minimum cost and got the optimal solution for the less computation, in problem 2 obtained better results than the other methods, in problem 3 for small size problem proposed method performed better but for large size problem results was not optimum. Jayachitra and Prasad [15] represented a comparison between cellular layout, virtual cellular layout and the existing functional layout of an industry. A genetic algorithm based on intra-cell formation procedure was used in the cellular layout design. To identify the suitability of a particular layout in a given environment, a typical manufacturing system modeled with computer software. The performance of each of the three layouts was analyzed by mean of operational parameters. The result from the simulation experiments indicated that the performance of virtual cellular layout was relatively superior to that of a functional layout and marginally inferior to a cellular layout.

Jannat et al. [19] addressed optimization of multi-objective facility layout problem. Two objectives was considered, minimizing the material handling cost (for this the Systematic Layout Planning is used) and maximizing the closeness rating score (to determine it, a relationship chart showing the degree of importance of having each department located adjacent to other used). Genetic algorithm (GA) with a computer program developed to solve the problem. According to authors developed algorithm can be applied to find the initial optimal facility location in a manufacturing environment and also able to handle a large variety of problem sizes. Duran et al. [20] addressed the problem of manufacturing cell formation using a modified particle swarm optimization (PSO) algorithm. The modified PSO did not based on vector of velocities as like standard PSO. The proposed algorithm used the concept of proportional likelihood with modifications, a technique that was used in data mining techniques. Some simulations were presented and compared. The criterion used to group the machines in cells was based on the minimization of inter-cell movements. The algorithm and its theoretical concepts were explained and illustrated for a cell formation problem with five instances of initial incidence matrix, 12 machines and 12 components. The computational results indicated that the particle swarm optimization algorithm was

able to find the optimal solutions on almost all instances. In all the generated cases, the algorithm found the best solution in almost 50% of the experiments.

Table 1: Review of meta-heuristic based FLP literature

References	Year	Method	Objectives			
			a	*b*	*c*	*d*
Reddy et al.	2012	PSO	√		√	√
Ohmori et al.	2010	PSO		√		
Miao and Xu	2009	GA+TS		√		
Longo et al.	2005	GA		√		
Liu et al.	2007	TS+SA		√		
Kulkarni and Shanker	2007	GA			√	
Jayachitra and Prasad	2010	GA			√	
Jannat et al.	2010	SLP+GA	√	√		
Duran et al.	2008	PSO			√	
Chang et al.	2009	TS			√	
Aiello et al.	2013	GA+Electre(MCDM)	√	√		√
Tuzkaya et al.	2013	GA,SA,HGASA				√
Zhang et al.	2009	GA			√	

Chang et al. [21] proposed a mathematical model to tackle the cell formation and cell layout simultaneously, with consideration of both alternative routing and production volume. Due to the combinatorial nature of this model, a hybrid tabu search algorithm was applied to solve it. The proposed algorithm not demanded a priori specification of the number of cells. Moreover, it was able to determine linear single-row layout or linear double-row layout. The results of the proposed method were compared with well-known approaches and these comparisons showed that it offers good solutions for the cell formation problems considering production volume, production sequence, and alternative process routing and cell layout. [12] Benabes et al. (2013) proposed a method to solve facility layout problem (FLP), this method was based on a design process divided into four steps: description, formulation, solving of the problem, and final decision. The proposed process combined a genetic algorithm with local optimization modules and was based on a multi-objective modular optimization strategy. The approach included an interactive environment in order to let the designer choose and improve an optimal solution according to his personal judgment and expertise. Developed method was applied to an industrial problem which deals with the search for an optimal layout of facilities in a shelter.

Alvarenga et al. [22] analyzed the facility layout problems in the situation of manufacturing environment and two procedures based on simulated annealing (SA) and tabu search (TS) were presented. For single-row layout problems having numbers of facilities 4, 10 and 11, both of the algorithms produced the optimal solutions. For others problems, they produced better solutions than those given in the literature. The algorithms produced the same results as in the literature for all the multi-row layout problems solved, with the exception of the one with 30 facilities. It was also observed by the author that the processing time of tabu search was smaller than the simulated annealing. The quality of the solutions produced by numerical tests indicates that both algorithms are promising tools for the treatment of the problem. Aiello et al. [23] proposed a methodology to solve layout problem based on multi-objective, block layout was determined by employing the multi-criteria decision making (MCDM) procedure Electre. Genetic algorithm (GA) was applied for optimization of alternative. Comparative experiments were done to show performance of the suggested algorithm.

Zhang et al. [24] worked on how to apply a unidirectional loop layout to optimize the facility layout in workshop. Firstly, they established a mathematic model of the optimization problem according to optimization objective and restriction condition. Secondly in order to make a solution of this unidirectional loop facility layout problem, author put forward an improved genetic algorithm based on multipoint crossover operator of parent and child competition, finally through the analysis of the practical example of facility layout optimization in blade workshop, Blade manufacturer wanted to optimize facility layout using the unidirectional loop model. There were nine units of machines of various kinds. Finally they get the optimized layout with developed algorithm. Youling et al. [25] proposed quadratic facility layout method by combining the thought of hierarchical analysis and quadratic assignment problem, which lays out independent-type units and dependent-type units successively through dividing facility units into independent-type units and dependent-type units. The models of quadratic facility layout method were constructed and ant colony algorithm with centroid method was used to solve the models. Quadratic facility layout method can be used to layout a workshop. They took the winding workshop of a company layout. The main limitation was the layout given by this method may not be absolute optimal solution.

Tuzkaya et al. [26] attempted to solve facility layout problem by using two different meta-heuristic approaches genetic algorithm (GA) and simulated annealing (SA) and a hybrid approach genetic algorithm/simulated annealing (HGASA). A case study problem was solved by these approaches. First, parameter values of GA and SA were determined and then the algorithms run for one hundred times. The comparison of the result of the algorithms was done based on their fitness values and calculation time requirements using the paired-test, mean and standard values. The results illustrated that SA performs better than the others in terms of the fitness values and the time requirements. In this study, authors also tested the performance of GA, SA and HGASA methodologies using some of the well-known test problems from the literature and obtained very close results to hose in literature. Singh [27] proposed an improved tabu search technique for solving facility layout problem. This technique was an improved version of conventional tabu search technique which incorporates three levels viz. intensification, reconstruction and solution acceptance. The new technique was tested and also compared with other meta-heuristic approaches. It was found that improved tabu search based approach provide comparative results. Shahin and Poormostafa [28] proposed an approach for facility layout design improvement and optimization. It was an integrated approach of simulation, fuzzy analytic hierarchy process (AHP), quality function deployment (QFD) and multiple criteria decision making (MCDM). Quantitative measure was determined by computer simulation and for qualitative measure analytical hierarchy process (AHP) was used. QFD implemented to determine weights of criteria and the importance of the alternatives in relation to quantitative and qualitative measures. TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) approach was used for ranking the alternatives and identifying the best alternative.

Reddy et al. [13] considered a multi objective criterion while designing the layout. Trial basis weights were assumed to objectives ranging from 0-1, the facility layout score was found as combined objective value. For optimization particle swarm optimization (PSO) technique was implemented and software was developed using C++. The alternative layouts were compared based on their combined objective function values. The lower the objective function better was the layout. According to author the developed software can be used as a practical tool for other types of layout also. Ohmori et al. [29] proposed the algorithm solving facility layout problem via particle swarm optimization (PSO). The proposed method did not use encoding techniques and instead, it searched coordinates of each department so that it can represent any possible layout. The objective of this model was to develop the layout that minimizes the total material handling costs between departments. Comparing the results obtained by the experiments, the proposed method achieved the results with better objective function, for small size problem. The major limitation was that it gives better results only for small size department, less than seven departments, not for large size departments.

Miao and Xu [30] represented a model for facility layout problem by considering handling cost and handling time. A hybrid algorithm which was the superposition of genetic algorithm and tabu search was proposed to solve the model. A recombination operator was designed through introducing the memory function of tabu search into simple genetic algorithm and a mutation operator also designed to improve climbing ability of the simple genetic algorithm. It was proved by case study that, this algorithm had better global search capacity and faster convergence rate. Mavridou and Pardalos [31] summarized the work that was done in implementing simulated annealing and genetic algorithms for solving the facility layout problem (FLP). Both heuristic approaches were successfully used to approximately solve difficult combinatorial optimization problems. For the FLP, the procedures seem to find sub-optimal solutions in a reasonable amount of computational time. It was expected that efficient parallel implementations of simulated annealing and genetic algorithms will be very useful for practitioners dealing with facility layout problems.

V. CONCLUSIONS AND FUTURE SCOPE OF WORK

From this review it is observed that particle swarm optimization (PSO), genetic algorithm (GA), ant colony optimization (ACO), simulated annealing (SA) and tabu search (TS) are used to optimize the multi-objective layout problem. Minimization of Material handling and total closeness between machines/department, Minimization of material handling cost, Minimization of Material flow and Minimizing total distance travel for material are considered as main objectives. Concurrent Engineering can also be implemented for solving Facility Layout Problems. It can be concluded Facility Layout Problems deals with wider range of objectives and also there are number of meta- heuristic approaches to deals with such kind of problems. Different approaches have their own merits and drawbacks too. So, hybrid approaches is a promising tool to overcome these drawbacks of a single meta-heuristic approaches.

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