Facility Layout Problem (FLP) and Intelligent Techniques: A Survey

M.A. Shouman* ,G.M. Nawara, A.H. Reyad***, Kh. EL-Darandaly******

* Assoc. Prof., Faculty of Computers and Informatics, Zagazig University
** Prof., Ind.Eng. Dept., Faculty of Eng., Zagazig University
*** Assis. Prof., Ind. Eng. Dept., Faculty of Eng., Zagazig University
**** Assis. Lecturer, Faculty of Computers and Informatics, Zagazig University

ABSTRACT
Facility layout problems (FLP) are a family of design problems involving the partition of a planar region into departments or work areas of known area, so as to minimize the costs associated with projected interactions between these departments. These costs may reflect material handling costs or preferences regarding adjacencies among departments. Facility layout problem is one of the truly difficult ill-structured, multicritria and combinatorial optimization problems. To cope with this type of problems, intelligent techniques such as expert systems, fuzzy logic, genetic algorithms and neural networks have been used. In this paper the facility layout problem is surveyed. Most of the conventional algorithms and intelligent techniques for solving FLP are presented. General remarks and tendencies have been reported

KEYWORDS: Expert systems, Fuzzy logic, Genetic algorithms, Neural networks, Facility layout, Combinatorial optimization.

INTRODUCTION
The facility layout problem, block layout, considers the assignment of facilities to locations so that the quantitative (qualitative) objective of the problem is minimized (maximized). The cost of the facility layout problem (FLP) takes place when assigning facilities to locations as well as when interactions occurring between pairs of facilities. The quantitative objective of the FLP is to minimize the material handling cost, while the qualitative objective is to maximize the subjective closeness rating by considering vital factors such as safety, flexibility, and noise, etc [1]. The facility layout problem is one of the best-studied problems in the field of combinatorial optimization. A number of formulations have been developed for the problem. More particularly the FLP has been modeled as [2] quadratic assignment problem (QAP), quadratic set covering problem, linear integer programming problem, mixed integer programming problem, and graph theoretic problem.

Quadratic Assignment Model
Koopmans and Beckman [3] were the first to model the problem of locating plants with material flow between them as a quadratic assignment problem (QAP). The name was so given because the objective function is a second-degree function of the variables and the constraints are linear functions of the variables. Consider the problem of allocating a set of facilities to a set of locations, with the objective to minimize the cost associated not only with the distance between locations but with the flow also. More specifically, given two $n*n$ matrices F=(f_{ij}) and D=(d_{kl}) where (f_{ij}) is the flow between the facility i and facility j, and d_{kl} is the distance between the location k and location l, and a set of integers N=(1,2,.. n), the QAP can be written as follows:

$$\min_{p \in \prod N} \sum \sum f_{ij} d_{p(i)p(j)}$$

$\prod_N$ where $\prod_N$ is the set of all permutations of N, and n is the number of facilities and locations [4]. The QAP has been frequently used to model the facility layout problem. However this does not mean that all the facility layout problems can be formulated as a QAP. For example, consider the machine layout problem in which the locations of the machines are not known initially, such problems cannot be formulated as QAP because the distance between the locations cannot be determined. The distance d_{ij} between locations j and i depends upon the sequence of arrangement of all other machines. This situation does not arise in layout problems in which the facilities are all of equal size, because the locations are all of the same area and hence the distance d_{jl} between j and l is independent of the facilities assigned of those locations.

Quadratic Set Covering Model (QSP)

Bazaraa [5] formulated facility layout problem as a quadratic set-covering model. In this solution formulation, the total area occupied by all facilities is divided into a number of blocks where each facility is assigned to exactly one location and each block is occupied by at most one facility. The distance between the locations is taken to be from centriods of the locations and the flow between facilities is minimized. The disadvantage of this approach is that the problem size increases as the total area occupied by all the facilities is divided into smaller blocks. The same can be said for Hillier and Connors suggestion [6] where the facilities can be partitioned into sub-facilities of equal area.

Linear Integer Programming Model

Several integer-programming formulations have been proposed for the facilities layout problem. Lawler [7] was the first to formulate the facility layout problem as a linear integer-programming model. He proved that his model is equivalent to QAP. QAP has $n^2 k_{ij}$ variables and 2n constraints while integer programming problem has $n^4 + 2n + 1$ constraints and $n^4 Y_{ijkl}$ where n is the number of plants/locations, X_{ij} is the integer variable of plant i at location j, and Y_{ijkl} is the integer variable of plant i at location j in arrangement k of location l. Love and Wang [8] proposed a simple integer programming formulation for the QAP in which the locations are given as points on a two dimensional plane and transportation costs are proportional to weighted rectangular distances. In this model, the location of facilities are specified by rectangular coordinates and uniquely specified. Computational experience for this model indicates that it is not suitable for problems with nine or more facilities.

Mixed Integer Programming Model

Kaufman and Broeckx [9] developed a linear mixed integer-programming model, which has the smallest number of variables and constraints among all integer-programming formulations of the QAP. The equivalence between QAP and the mixed integer programming has been proposed through this model and Burkard [10]. This formulation has n^2 (0-1) and n^2 continuous variables and $n^2 + 2n$ constraints. Also, this equivalence has been proofed by many researchers [11,12,13,14]. Rithzman et al [15] formulated a large mixed integer goal-programming model for assigning offices in buildings. They also developed a computer programs to evaluate the performance of solutions with respect to six conflicting objectives.

Graph-Theoretic Approach

In this approach it is assumed that the desirability of locating each pair of facilities adjacent to each other is known (Flouds and Robinson [16]). In this model a closeness rating indicating desirability of locating facility i adjacent to facility j is assumed. The model seeks to maximize the closeness rating of the facilities. Rosenblatt [17] developed a model, which minimizes the transportation cost of material and maximizes a closeness rating measure, which are two conflicting objectives. In this model, a heuristic algorithm is developed to solve the problem.

CONVEVTIONAL SOLUTION ALGORITHM

Since the late 1950s a number of algorithms have been developed to solve the facility layout problem. These algorithms may be classified as optimal algorithms and sub-optimal algorithms.

Optimal Algorithms

Many different optimal algorithms have been developed to solve QAP. These algorithms are branch and bound algorithms [5,7,10,18,19,20,21,22,23,24] and cutting plane algorithms [10,12,13,25,26]. In branch and bound algorithms, the solution procedure proceed on the basis of stage by stage or parallel search of single assignment or pairs of assignments of facilities to locations. At each stage back tracking occurs, certain assignments are excluded and the forward search process is resumed. All exact algorithms have high memory and computational requirements. The main difference between these algorithms is the lower bounds upon which potential solutions are evaluated and problem size that the algorithm can solve. The optimal branch and bound and cutting plane algorithms have high time and storage complexity. The largest facility layout problem solved optimally by a cutting plane algorithm is the layout problem of eight facilities. A common experience with the optimal algorithms is that the optimal solution is found early in the branching process but is not verified until a substantially high number of solutions have been enumerated. Two criteria for the premature termination of branch and bound process are considered. The first is based on predetermined time limits while the second is based on the quality of upper bound.

Sub-Optimal Algorithms

Sub-optimal algorithms are crucial request as solution procedures where memory and computational time requirement are high for optimal algorithms in addition to constraint on the maximum number of facilities solved by these algorithms (15 facilities [27]). Many researchers began to develop sub-optimal algorithms to deal with QAP of FLP. These sub-optimal are classified as, construction algorithm, improvement algorithm, hybrid algorithm, and graph theoretic algorithm.

Construction algorithms

In construction algorithms a solution is constructed by assigning facilities to a site, one at a time, until the complete layout is obtained. Many more construction algorithms are presented [6,28,29,30,31,32,33,34,35,36,37]. These algorithms are named as HC66, ALDEP, CORELAP, RMA, MAT, PLANET, LSP, LINEAR PLACEMENT ALGORITHM, FATE, INLAYT, and FLAT respectively. Minimum total flow between facilities, minimum total transportation cost, and facility adjacent desirability are common objective of the aforementioned construction algorithms.

Improvement algorithms

In improvement algorithms [6,38,39,40,41,42,43,44] there is always an initial solution, which is often randomly generated. Based on this initial solution, systematic exchanges between facilities are made and the results are evaluated. The exchange that produces the best solution is retained and the procedure continues until the solution cannot be improved. Hence the solution quality of improvement algorithms depends upon the initial layout evaluated. CRAFT, COFAD, and REVISED HILLER algorithms are examples of improvement algorithms.

Hybrid algorithms

In hybrid algorithm [12,25,26,45,46] the solution of QAP is determined by using a combination of two optimal or sub-optimal algorithms. Such combination of algorithms is essential in some cases to improve solution quality. This classification is extended to include certain algorithms such as those of Elshafei [47] and Scriabin and Vergin [45], which use the principal of construction algorithms and improvement algorithms. FLAC and DISCON are examples of such hybrid algorithms. Such solution procedures are characterized by their ability to produce good quality solutions.

Graph theoretic algorithms

Graph theoretic algorithms identify maximal planar subgroups of a weighted graph that show the relationships between the facilities. The dual of a maximal planar sub graph determines the layout of the facilities. Seppanen and Moore [48,49] proposed graph-theoretic solutions procedure in which a heuristic algorithm, which uses this strategy, was also presented. The algorithm determines the maximum spanning tree based on the weighted graph. With the help of one edge adding process, the maximum spanning tree is the used to obtain a maximal planar sub graph. The dual of the maximal planar sub graph determines a layout of the facilities. Branch and bound algorithms which is presented by Foulds and Robinson [16,50], Deltahedron algorithm developed by Foulds and Robinson also, and wheel expansion algorithm introduced by Eades et al [51] are the most popular graph theoretic algorithm used to solve QAP.

The major drawbacks of the aforementioned approaches lie in the fact that the search for the best layout is not very efficient and the multi-objective nature are not considered in the problem [6]. As a matter of fact, Facility layout problem can be considered one of the truly difficult ill-structured, multi-critria and combinatorial optimization problems. Many researchers still finding out for new and recent developments rather than conventional approaches to overcome the aforementioned drawbacks. Intelligent techniques such as expert systems, fuzzy logic, genetic algorithms and neural networks have been used as new advancements for the tackled problem. In this paper we review most of the recent developments regarding these intelligent techniques for solving facility layout.

INTELLIGENT TECHNIQUES FOR FLP

Intelligent techniques were introduced to the field of facilities layout in the early 1980s. Most of these systems, classified according to the used technique, are briefly reviewed in the following paragraphs.

Expert Systems and FLP

Expert systems are considered as one of a conceptual breakthrough in artificial intelligence (AI) field [52]. In expert systems the problem-solving power of a program comes from the knowledge it posses, not from the formalisms and inference schemes it employs. An expert system (ES) is defined as a special purpose computer program used to emulate the decision making process of a human expert in a specific knowledge domain of limited scope. The main components of an expert system are user interface, explanation subsystem, knowledge acquisition subsystem, knowledge base, and inference engine. Expert systems represent a revolutionary transition from the traditional data processing to a knowledge processing. They offer an environment for incorporating the good capabilities of humans and the power of computers. The main privileges [52,53] of expert systems are; they can be used to solve unstructured problems and when no procedure exists, they have the ability of handling a symbolic information and applying a systematic reasoning process with a very large knowledge base, they can accommodate new expertise whenever new knowledge is identified and explain their recommendations, they provide expert level consultative services to users for productivity improvement and reduce the company's reliance on human experts by capturing expert knowledge and storing it in computers, they are often cost effective when human expertise is very expensive, not available, or contradictory, objective, not biased or prejudiced to a predetermined goal state, and does not jump to conclusions, expert systems are not influenced by perceptions that are not relevant. Although expert systems have several advantages, they also have some drawbacks where; the human expert must be available, able to articulate, and explain the rules used in solving problems, the rules articulated must be cogent, correct, consistent, the development of an expert system may be a lengthy process and depending on the problem domain, and expert systems are not good at representing temporal knowledge, representing spatial knowledge, performing commonsense reasoning, handling inconsistent knowledge, and recognizing the limits of their ability. Several expert systems have been proposed for the facility layout problem. Most of these systems are briefly reviewed in the following paragraphs.

FN84 Fisher and Nof [54] introduced, FADES, a knowledge-based approach for facilities design. FADES is an ES designed for solving general facility design problems, selecting equipment that meets the required technology level, and performing economic analysis. It consists of a knowledge base, a PROLOG interpreter and a database management system relevant to the application concerned. The database consists of economic models, algorithms and rules for selecting equipment, developing relationship rating between facilities, selecting and invoking the appropriate algorithm, etc. The knowledge is represented using first order predicate logic. The PROLOG interpreter employs forward-chaining depth-first search in order to show that the negated goal does not match any of the assertions in the database. The input information is flow and distance data, and materials handling cost matrix.

The solution to the layout problem is based on the relationship chart, which is evaluated by a series of expert rules.

KKMM87 Kumara et al. [55] have developed a heuristic-based ES. They have defined the facilities layout problem as a multi-objective problem and have outlined a methodology to handle the qualitative constraints in conjunction with heuristic procedures for quantitative parameters. The input information is the number of departments and their corresponding areas. The knowledge base invokes a FORTRAN program, which draws a square grid, divides the screen into equal areas, and generates the adjacent. The solution is a layout with one-directional material flow on the graphics screen and includes an explanation of the reason for each assignment.

KKMM88 Kumara and Kashyab [56] have developed, IFLAPS, an intelligent facilities layout planning and analysis system. IFLAPS has two basic modules: a) an expert system and b) a pattern recognition system. In the expert system, the heuristics used are based on the augmented transition networks of natural language processing. In the pattern recognition system, production rules are used to capture the expert knowledge. The ES module uses three types of assignment rules to determine the adjacency of two facilities. Next the pattern recognition determines the facility to be assigned first in the floor plan. The method does not involve paired comparisons between departments or the overall relationship between various facilities. IFLAPS is written in PROLOG.

MT89 Malakooti and Tsurushima [1] have developed an ES for multiple-criteria facility layout problems. Their approach is based on expert systems and multiple-criteria decision-making (MCDM). The expert system interacts with the decision-maker (DM), and reflects the DM's preferences in the selection of rules and priorities. The inference engine is a forward-chaining reasoning procedure. The approach consists of two parts: (a) construction of a layout based on a set of rules and restrictions, and (b) improvement of the layout based on interaction with DM. The MCDM expert system approach considers and incorporates the multiple-criteria in these two parts as follows. In (a) it uses priorities on the selection of rules, adjacency of departments, and departments for construction purposes. In (b) it uses different objectives such as materials handling cost, flexibility, and materials handling time for paired comparison of generated layouts for improvement purposes.

HK90 Heragu and Kusiak [57] have developed an ES (KBML) for machine layout in automated manufacturing systems. KMBL combines the expert system and optimization approaches to solve the layout problem. It first selects an appropriate model and algorithm for a given problem. Then it solves the problem using the selected algorithm and the solution produced is evaluated. If the solution is implemental, the expert system accepts it and provides it to the user. If the solution is not implemental, it is either modified appropriately or the input parameters are modified and the algorithm is re-applied for a new solution generation. This new solution is examined for satisfaction. The knowledge base in KMBL consists of 59 rules. A forward-chaining inference strategy is utilized in the system.

AD90 Abdou and Dutta [58**]** have developed an expert system approach to define appropriate layouts of machining facilities under specific combinations of manufacturing and materials handling systems. The knowledge base incorporates six factors relating product variety and quantity, degrees of flexibility, level of automation, materials handling system, work-in-process, and environmental considerations. The system drives the relationship chart through an ordered system of queries, rather than assuming that the chart is a given input to the program. The system operates in tandem mode and interfaces with both algorithms to optimize the materials handling equipment, and standard layout generation packages (ALDEP & CORELAP) to derive a suitable layout, which is then examined for feasibility based on space constraints.

ST94 Sirnaovakul and Thajchayapong [59] have developed a construction model for facility layout using AI techniques. The designed system consists of a pattern allocation, a heuristic search and a knowledge base system. The system first generates alternative layouts by using a pattern allocation. The heuristic search seeks for the best layout from these generated alternatives. The heuristic function, or closeness weight, is also used for directing the search process to the most profitable choice of layout by acquiring knowledge from the knowledge base. A forward-chaining strategy is utilized by the system. .

H97 Harraz [60] has developed a knowledge-based decision support system for facility layout. The system works in a tandem mode. It combines a rule-based module with an optimization module. The rule-based module enables the end user to assign different priorities for criteria and generates a layout based on a set of rules. The resultant layout is seeded optionally to the improvement algorithm to find a better configuration for the solution. The improvement module is based on the simulated annealing (SA) global optimization algorithm.

Fuzzy Systems and FLP

Fuzzy set theory provides a formal system for representing and reasoning with uncertain information. It was pioneered by Lotfi Zadeh in approximately 1965. In this system, set membership is not" all or nothing," but rather is defined via a no binary membership function. Fuzzy sets are actually functions that map a value that might be a member of the set to a number between zero and one indicating its actual degree of membership. A degree of zero means the value is not in the set, while degree of one means the value of the set is completely represented. This produces a curve across the members of the set. The center of the fuzzy modeling technique is the idea of a linguistic variable. At its root, a linguistic variable is the name of the fuzzy set. A linguistic variable also carries with it the concept of fuzzy set qualifiers. These qualifiers change the shape of fuzzy sets in predictable ways and function in the same fashion as adverbs and adjectives in the English language [61]. In applying the fuzzy technique, the following are typically encountered [62].

1- Selection the set of both input/output linguistic variables that are natural to the application and whose crisp values are available.
2- Determenation of membership functions for all linguistic variables labels.
3- Selection of both fuzzification, crisp inputs are converted into fuzzy representations, technique and defuzzification, the propagated fuzzy representation is converted to a set of crisp values, technique.
4- Development of a knowledge base of fuzzy rules, fuzzy inference strategy, system prototyping, testing, and documentation.

Several implementations of the fuzzy logic have been proposed for the facility layout problem. Most of these systems are briefly reviewed in the following paragraphs.

EWK87 Evans et al [63] have developed a construction-type fuzzy linguistic heuristic for the location of the departments within a facility. This heuristic utilizes imprecise descriptors for two distinct design categories: closeness and importance, expressed in the form of fuzzy relations for every pairs of departments. The heuristic is a crude one since it only addresses the problem of the order in which the departments should enter into the layout. The actual placement of departments must be done manually. In addition, the heuristic employs only a small fraction of the total information given in the relation matrix.

RR93 Raoot and Rakshit [64] have developed a linguistic pattern approach for multiple criteria facility layout problems. A multiple criteria model is formulated using the basic concept of linguistic pattern and a heuristic procedure is proposed to generate a set of efficient alternative layouts. Facility layout selection from the set of alternatives, which satisfy different objectives and restrictions to known degrees, is considered as a MCDM problem and the ELECTRE method, based on out ranking relations approach, is used to select the best layout.

DM96 Dweiri and Meier [65] have established a vigorous methodology, based on fuzzy set theory, to improve the facilities layout process. The AHP is used to find the weights of both qualitative and quantitative factors, which affect the closeness rating between departments in a plant. FUZZY, a computer program developed based on the fuzzy decision-making system (FDMS), is used to generate the activity relationship charts. These charts are used by FZYCRLP, a modified version of CORELAP, to develop the layouts. FELAP, another program based on FDMS, is used to evaluate the layouts. This evaluation method uses the distances and the relationships between departments to score the layout.

WW99 Whyte and Wilhelm [66] developed a new heuristic approach for generating block layouts of facilities. It uses space-filling curves to determine the placement of departmental areas, and fuzzy linguistic assessments determine the entry order into the layout. The heuristic has been implemented in Visual Basic and has been tested against layouts generated by both SLP and commercially available layout software. The solutions found by this heuristic have been consistent with those yielded by comparable methods. Probably one of the biggest advantages offered by the new heuristic is its ability to use the binary fuzzy relations (B8R's) to consider required non-adjacencies between departments during the layout process.

Neural Networks and FLP

Artificial neural network (ANN) is a computational structure inspired by the study of biological neural processing. The first step toward artificial neural networks came in 1943 when Warren McCulloch, a neuro-physiologist, and a young mathematician, Walter Pitts, wrote a paper on how neurons might work. They modeled a simple neural network with electrical circuit [67]. ANN is a structure composed of a number of interconnected units (artificial neurons). Each unit has an input/output (I/O) characteristic and implements a local computation or function. The output of any unit is determined by its I/O characteristic, its interconnection to other units, and external inputs. The network topology, the individual neuron characteristics, the learning strategy, and the training data determine the functionality achieved [68]. The main features that make ANNs advantages over computational techniques, as mentioned in [62] are; information is distributed over a field of nodes, their ability to learn and allow extensive knowledge indexing, and their suitability for processing noisy, incomplete, or inconsistent data and mimic human learning processes. Although ANNs have several advantages, they also have some drawbacks [62] where; no clear rules, or design guidelines for arbitrary application, no definite way to access the internal operation of the network, training may be difficult or impossible, and it is not easy to predict future network performance.

TBT96 Tsuchiya et al. [69] have developed a near-optimum parallel algorithm based on two-dimensional maximum neural network for facility layout problems. The developed algorithm uses N x N neurons for an N-facility layout problem. The simulation results demonstrated that the developed algorithm is capable of generating better solutions over the existing algorithms for some of the most widely used benchmark problems.

Genetic Algorithms and FLP

Genetic algorithms (GA) were first introduced by John Holland at the university of Michigan 1n 1975. Genetic algorithms are search algorithms based on the mechanics of natural selection and natural genetics [70]. GA tries to imitate the development of new and better populations among different species during evolution. Unlike most of the heuristic search algorithms, GA conducts the search through the information of a population consisting of a subset of individuals, i.e. solutions. Each solution is associated with the fitness value, which is the objective function value of the solution. Solutions to optimization problems can often be coded to strings of finite length. The genetic algorithms work on these strings. The encoding is done through the structure named chromosomes, where each chromosome is made up of units call genes. Many factors are strongly affecting the efficiency of genetic algorithms. These factors are; the representation of the solution by strings, generation of the initial population, the selection of individuals in an old population that will be allowed to affect the individuals of a new population, and the genetic operator that are used to recombine the genetic heritage from the parents to produce children. The selection of individuals that will be allowed to affect the generation is based on the fitness of the individuals. However, a genetic algorithm procedure is described as mentioned in [71] as

Input: a problem instance

Output: a sub-optimal solution

1. t=0, initialize P_t, and evaluate the fitness of the individuals in P_t
2. while (terminating condition is not satisfied) do
   a- t=t+1
   b- select P_t, recombine P_t, and evaluate P_t
3. output the best solution in the population as the sub-optimal solution

where P_t denote the population at time t.

GAs differ from traditional optimization and research procedures in four ways [72]; they work with a coding of the parameter set, not the parameters themselves, start search from a population points, not a single point, use payoff information, not derivatives or other auxiliary knowledge, and use probabilistic transition rules, not deterministic rules. However, several implementations of genetic algorithms have been proposed for facility layout problem. Most of the se approaches are briefly reviewed in the following section.

T92 Tam [73] developed a genetic algorithm approach for solving facility layout problem. He used slicing trees as a coding scheme for the facility layout. For FLP, a slicing structure is constructed by recursively partitioning a rectangular block in such a way that each rectangular partition in the slicing structure corresponds to the space allocated to a facility. The space of all layouts is defined as the set of all slicing trees that can be generated by rearranging the cuts of a slicing tree. The used symbolic representation takes into account both the area and shape constraints of individual facilities. The genetic algorithm approach was compared with a local search technique (Hill-climbing) in solving problems with size ranging from 12-30 facilities. The results demonstrated that a genetic algorithm could be a viable tool to solve large-scale layout problems.
CT94 Chan and Tansri [74] applied GA to FLP. Three different GA crossover operators: PMX (Partially Matched Crossover), OX (Order Crossover), and CX (Cycle Crossover) were studied. The order operators' performance was found to be PMX, OX, and CX. The PMX operator worked well and consistently for different plant sizes. The OX operator worked comparably at smaller plant sizes (=< 9), but its performance dropped significantly for larger plants. The CX operator, on the other hand, was the worst due to its early convergence. General guidelines in setting GA parameters have also been proposed based on a large number of numerical experiments.
CV94 Conway and Venkataramanan [75] developed a genetic algorithm approach for dynamic facility layout problem. Dynamic facility layout over time is a combinatorial problem for which optimal solution can be found for only very small problems. The developed genetic algorithm has the ability to include multiple constraints as well as non-linear and non-convex objective functions. The algorithm was tested with two sample problems. The results demonstrated that genetic algorithms could be a viable tool to solve constrained dynamic facility layout problems.
SC96 Sulung and Chan [76] proposed three two-dimensional crossover operators based on the partial matched crossover (PMX) operator, namely PMX-HV, PMX-2PT, and PMX-1PT. The PMX-HV operator selects a horizontal or vertical cutting edge randomly for crossover. The PMX-2PT selects two points along the boundary of the plant to establish a cutting edge. The PMX-1PT starts from one point along boundary of the plant and travels randomly to generate a cutting edge. The PMX operator and the three new operators were applied to a large 36-location plant. Extensive experiments were performed and the performance of these operators was evaluated and compared. The performance of these three new operators was not as good as the PMX operator due to the significant reduction of number of possible crossing boundaries.
CGT96 Cheng et al [77] addressed the loop layout design problem for flexible manufacturing system and developed a hybrid approach of genetic algorithms and a local search technique (neighborhood search) for solving the problem. They designed a neighbor search heuristic based mutation in order to find out improved offspring. Permutation coding scheme was adopted to represent loop layout design. Also, PMX (partially mapped crossover) operator was used. Both of minsum and minmax congestion measures are tested for randomly generated problem with 15 machine and 9 parts. Preliminary computational results showed that minsum approach outperformed minmax. The proposed procedure was also tested with different parameters setting to investigate how the impact on the performance of the algorithm. The results showed that mutation played a critical role in the proposed genetic algorithm because it was implemented as neighborhood search.
KFH98 Kochhair et al [78] developed, HOPE, a GA based algorithm for solving single-floor facility layout problem. Their model considered departments of both equal and unequal sizes. They used an order based encoding scheme to represent FLP. HOPE performance was evaluated using several test problems available in the literature. The results indicated that GA might provide a better alternative in a realistic environment where the objective is to find a number of reasonably good layouts.
KH98 Kochhair Heragu [79] developed, MULTI-HOPE, a GA based-algorithm for generating block layouts for multiple-floor layout problems. MULTI-HOPE was an extension of their algorithm, HOPE, described in [78]. MULTI-HOPE performance was evaluated using several test problems. The results indicated that MULTI-HOPE produced, on average, a solution quality better than existing multi-floor layout algorithm.
HYS99 Hamamoto et al [80] developed a genetic algorithm-based facility layout method with an embedded simulation model for the pharmaceutical industry. This method allows the user to select the objectives that are important in each particular layout design in the pharmaceutical industry. The experimental results showed that the proposed method outperformed all existing computer layout

algorithms such as CRAFT, CORELAP and BLOCPLAN as well as human designers in maximizing the throughput rate and minimizing the traveling time/trip.

Intelligent Hybrid Systems and FLP

Since its emergence in the 1950s, AI has provided several techniques. Each of them is capable of solving a certain type of problems. Hybrid approach aims to integrate more than one technique when solving a specific problem. Hybrid approach is a promising tool for intelligent systems as the weakness of some techniques can be offset by the strengths of other techniques.

PO92 Pham and Onder [81] have developed a knowledge-based system for optimum workplace design. The system is constructed using a commercially available hybrid development tool. It is interfaced to a database of anthropometrical data and an optimization program. The optimization program employs a genetic algorithm. This combination of knowledge-base technology, genetic optimization methods, and database technology has proved to be an effective way to build powerful knowledge-based systems for solving complex ergonomic design problems.

CGT95 Cheng et al [82] introduced the concept of fuzzy inter-flow into facility layout design problem and addressed fuzzy facility layout problem, where uncertainty of material flows among facilities is represented as trapezoidal fuzzy members. They developed a genetic algorithm for solving such hard fuzzy combinatorial problem. Polish expression was adopted as the coding scheme of chromosome. The condition of legality for polish expression coding and the condition for searching cut point in a chromosome were given. Based on these conditions, effective initialization procedure and layout construction procedures were built. Fuzzy ranking method was used to select the best layout in fuzzy context. A penalty to the violation of aspect ratio for each facility is used to guide genetic search effectively towards to the promising part of solution space. The possibility theory and fuzzy integral were used to meaningfully interpret the fuzzy results. The simulation results demonstrated that genetic algorithm and fuzziness approach could be efficient tools to solve large-scale layout problem.

BA96 Badiru and Arif [83] developed, FLEXEPRET, a fuzzy-integrated expert system for facility layout. FLEXEPRET considers the multi-criteria nature of the layout problem and the fuzziness of the input data through the integration of an expert system and a fuzzy algorithm with a commercial facility layout program (BLOCPLAN). The system generates the best layout that satisfies the qualitative as well as the quantitative constraints on the layout problem. The commercial software, VP-Expert, was used as the expert system development shell.

C99 Chunag [84] developed a cascade BAM (Bi-directional Associative Memories) neural expert system to conceptual design for facility layout. This improved BAM structure functions as an expert system for conceptual facility layout or for preliminary construction layout design. The system has the capability of incrementally learning layout design examples for a given set of constraints. The cascade BAM incremental learning methodology, which distinguishes this system from the more frequently used Back propagation Network (BPN) learning system, creates effective multi-bi-directional generalization behavior from qualitative, goal-driven layout design experience. This study has demonstrated how a BAM neural network can be applied to create a dynamic knowledge base through its bidirectionality and incrementally of the learning-from-examples, and then to generalize a solution through the rules stored in the created knowledge base.

CONCLUSIONS

The paper summarized the most recent developments of conventional algorithms and intelligent techniques for NP-hard FLP. From the above discussion, it is clear that the conventional sub-optimal algorithms are solvers of good quality solutions for FLP, require very low computational requirement i.e low memory and computational time requirement, able to solve problems of higher facilities and of equal and unequal areas, provide the user flexibility with respect to fixing facility locations, facility configurations, etc. For intelligent techniques, expert systems and fuzzy systems are good solvers for NP-hard FLP when it is treated as multi-criteria decision problem while genetic algorithms are good solvers when NP-hard FLP is treated as single criterion decision problem. In these techniques the intelligent search and heuristics used are significantly viable tools to solve large-scale layout problems, dynamic problems, provide better solution in a realistic environment. Also, the intelligent hybrid systems are promising solver tools for intelligent systems as the weakness of some techniques can be offset by the strengths of other techniques.

REFERENCES

1- Malakooti, B., and Tsurushima, A., "An Expert System Using Priorities for Solving Multiple-Criteria Facility Layout Problems" Int. J. Prod. Res. Vol. 27, No. 5, (1989) pp: 793-808.
2- Kusiak, A., and Heragu, S.S., " The Facility Layout Problem" EJOR, Vol.29, (1987), pp: 229-251.
3- Koopmans, T.C., and Beckman, M., " Assignment Problems and The Location of Economic Activities" Econometrica, Vol.25, (1957), pp: 53-67.
4- P.M., Pardalos, F., Rentl, and H.Wolkowicz, "The Quadratic Assignment Problem: A Survey and Recent Developments", Quadratic Assignment and Related Problems, P.M. Pardalos, and H. Wolkowicz (eds). DIMACS Series on Discrete Mathematics and Theoretical Computer Science, Vol.16, American Mathematical Society, (1994), pp: 1-42.
5- Bazara, M.S., "Computerized Layout Design: A Branch and Bound Approach" AIIE Transactions, Vol.7, No.4, (1975), pp: 432-437.
6- Hiller, F.S., and Connors, M.M., "Quadratic Assignment Problem Algorithms and The Location of Indivisible Facilities" Management Science, Vol.13, (1966), pp: 42-57.
7- Lawler, E.L., "The Quadratic Assignment Problem" Management Science, Vol.9, (1963), pp: 586-599.
8- Love, R.F., and Wong, J.W., "Solving Quadratic Assignment Problems with Rectilinear Distances and Integer Programming" Naval Research Logistics Quarterly, Vol.23, (1976), pp: 623-627.
9- Kaufman, L., and Broeckx, F., "An Algorithm for The Quadratic Assignment Problem Using Bender's Decomposition" EJOR, Vol. 2, (1978), pp: 204-211.
10- Burkard, R.E., "Locations With Spatial Interaction-Quadratic Assignment Problem", in: R.L. Francis and P.B. Mirchandani (eds.), Discrete Location Theory. Academic Press, New York, (1984).
11- Balas, E., and Mazzola, J.B., "Quadratic 0-1 Programming by a New Linearization", presented at the TIMS/ORSA meeting, Washington, DC, (1980).
12- Bazara, M.S., and Sherali, M.D., "Bender's Partitioning Scheme Applied to a New Formulation of The Quadratic Assignment Problem" Naval Research Logistics Quarteraly, Vol. 27, No. 1, (1980), pp: 29-41.
13- Burkard, R.E., and Bonninger, T.," A Heuristic for Quadratic Boolean Program With Applications to Quadratic Assignment Problems", EJOR, Vol.13, (1983), pp: 374-386.
14- Frieze, A.M., and Yadegar, J.,"On The Quadratic Assignment Problem" Discrete Applied Mathematics, Vol. 5, (1983), pp: 89-98.
15- Ritzman, L.P., Bradford, J., and Jacobs, R., "A Multiple Objective Approach to Space Planning for Academic Facilities" Management Science, Vol. 25, No. 9, (1979), pp: 895-906.
16- Foulds, L.R., and Robinson, D.F, "A Strategy for Solving The Plant Layout Problem" Operations Research Quarterly, Vol. 27, No. 4, (1976), pp: 845-855.
17- Rosenblatt, M.J., "The Facilities Layout Problem: A Multi-goal approach", Int. J. Prod. Res., Vol. 17. No. 4, (1979), pp: 323-332.
18- Gilmore, P.C., " Optimal and Sub-Optimal Algorithms for The Quadratic Assignment Problem" Journal of the society for industrial and applied mathematics, Vol. 10, (1962), pp: 305-313.
19- Pierce, J.F., and Crowston, W.R., "Tree-Search Algorithms for Quadratic Assignment Problems" Naval Research Quarterly, Vol.18, (1971), pp: 1-36.
20- Land, A.H.,"A Problem of Assignment With Interrelated Costs" Operations Research Quarterly, Vol.14, (1963), pp: 185-198.
21- Gavett, J.W., and Plyter, N.V., "The Optimal Assignment of Facilities to Locations by Branch and Bound", Operations Research, Vol.14, (1966), pp: 210-232.
22- Lavalle, I., and Roucairol, C., "Parallel Branch and Bound Algorithms" presented at EURO VIII, Bologna, Italy, (1985).
23- Graves, G.W., and Whinston, A.B., "An Algorithms for Quadratic Assignment Problem" Management Science, Vol.17, No.7, (1970), pp: 453-471.
24- Bazara, M.S., and Elsfafei, A.N., "An Exact Branch and Bound Procedure for Quadratic Assignment Problems" Naval Research Logistics Quarterly, Vol.26, (1979), pp: 109-121.
25- Burkard, R.E., and Stratman, K.H., " Numerical Investigations on Quadratic Assignment Problems" Naval Research Logistics Quarterly, Vol.25, (1978), pp: 129-144.

26- Bazara, M.S., and Kirca, O., “A Branch and Bound-Based Heuristic for Solving QAP” Naval Research Logistics Quarterly, Vol.30, (1983), pp: 287-304.
27- Kusiak, A., and Heragu, S.S., “The Facility Layout Problem” EJOR, Vol. 29, (1987), pp: 229-251.
28- Seeof, J.M., and Evans, W.O., “Automated Layout Design Program” The Journal of Industrial Engineering, Vol.18, No.2, (1967), pp: 690-695.
29- Lee, R., and Moore, J.M., “CORELAP-Computerized Relationship Layout Planning” Journal of Industrial Engineering, Vol.18, (1967), pp: 195-200.
30- Murther, R., and McPherson, K., “Four Approaches to Computerized Layout Planning” Industrial Engineering, February, (1970), pp: 39-42.
31- Edward, H.K., Gillett, B.E., and Hale, M.C., “Modular Allocation Technique (MAT)” Management Science, Vol.17, No.3, (1970), pp: 161-169.
32- Deisenroth, M.P., and Apple, J.M., “A Computerized Plant Analysis and Evaluation Technique” Technical paper, Annual AIIE, Conference, Norecross, GA. (1972).
33- Zoller, K., and Adendorff, K., “Layout Planning by Computer Simulation” AIIE Transactions, Vol.4, No.2, (1972), pp: 116-125.
34- Neghabat, F., “An Efficient Equipment Layout Algorithm” Operations Research, Vol. 22, (1974), pp: 622-628.
35- Block, T.E., “FATE: A New Construction Algorithm for Facilities Layout” Journal of Engineering Production, Vol.2, (1978), pp: 111-120.
36- O’Brien, C., and Abdel Barr, S.E.Z., “An Interactive Approach to Computer Aided Facility Layout” Int. J prod. Res. Vol.18, No.2, (1980), pp: 201-211.
37- Heragu, S., and Kusiak, A. “A Construction Algorithm for the Facility Layout Problem”, working paper #14/86, Department of mechanical and industrial engineering, University of Manitoba, Winnipeg, Manitoba, Canada (1986).
38- Armour, G.C, and Buffa, E.S., “A Heuristic Algorithm and Simulation Approach to Relative Allocation of Facilities” Management Science, Vol.9, No.2, (1963), pp: 294-300.
39- Hiller, F.S., “Quantitative Tools for Plant Layout Analysis” Journal of Industrial Engineering, Vol. 14, (1963), pp: 33-40.
40- Vollmann, T.E., Nugent, C.E., and Zartler, “A Computerized Model for Office Layout” The Journal of Industrial Engineering, Vol.19, (1968), pp: 321-327.
41- Nugent, C.E., Vollmann, T.E., and Ruml, J., “An Experimental Comparison of Techniques for the Assignment of Facilities to Locations” Operations Research, Vol.16, (1968), pp: 150-173.
42- Khalil, T.M., “Facilities Relative Allocation Technique (FRAT)” Int. J. Prod. Res., Vol.11, No.2, (1973), pp: 183-194.
43- Tompkins, J.A., and Reed, R. Jr., “An Applied Model for the Facilities Design Problem” Int. J. Prod. Res., Vol. 14, No. 5, (1976), pp: 583-595.
44- Picone, C.J., and Wilhelm, W.E., “Perturbation Scheme to Improve Hiller’s Solution to the Facilities Layout Problem” Management Science, Vol.30, No.10, (1984), pp: 1238-1249.
45- Scriabin, M., and Vergin, C.R., “Comparison of Computer Algorithms and Visual Based Methods for Plant Layout.” Management Science, Vol.22, No.2, (1985), pp: 172-181.
46- Denzer, Z., “DISCON: A New Method for the Layout Problem” Operations Research, Vol.25, No.6, (1980), pp: 1375-1384.
47- Elsfafei, A.N., “Hospital Layout as a Quadratic Assignment Problem” Operations Research Quarterly, Vol. 28, No.1, (1977), pp: 167-179.
48- Seppannen, J.J., and Moore, J.M., “ Facilities Planning With Graph Theory” Management Science, Vol.17, No.4, (1970), pp242-253.
49- Seppannen, J.J., and Moore, J.M., “String Processing Algorithms for Plant Layout Problems” Int. J. Prod. Res., Vol.13, No.3, (1975), pp: 239-254.
50- Foulds, L.R., and Robinson, D.F., “Graph Theoretic Heuristics for the Plant Layout Problem”, Int. J. Prod. Res., Vol.16. No.1, (1978), pp: 27-37.
51- Eades, P., Foulds, L.R., and Giffin, J., “An Efficient Heuristic for Identifying a Maximum Weight Planar Subgraph”, in: Lecture Notes in Mathematics No. 952 (Combinatorial Mathematics IX), Springer, Berlin. (1982).
52- EL-Drandaly, K.A, “ Water Resources Development Using Artificial Intelligence and Expert Systems Approaches”, unpublished Msc. Thesis, Zagazig university, (1996).

53-Huang, s. h. and Zhang, h.,"Neural-Expert Hybrid Approach for Intelligent Manufacturing : A Survey" Computers in Industry, Vol.26, (1995), pp: 107-126.
54-Fisher, E.L. and Nof, S.Y., "FADES: Knowledge-Based Facility Design" Proceedings of international industrial engineering conference, Chicago, (1984), pp: 74-85.
55-Kumara, S. R, Kashyap, R. L., and Moodie, C. L., " Expert System for Industrial Facilities Layout Planning and Analysis" Computers Ind. Engng. , Vol. 12, No. 2, (1987), pp: 143-152.
56-Kumara, S. R., and Kashyap, R. L. " Application of Expert Systems and Pattern Recognition Methodologies to Facilities Layout Planning", Int. J. Prod. Res. Vol. 26, (1988), pp: 905-930.
57-Heragu, S., and Kusiak A. " Machine Layout: An Optimization and Knowledge-Based Approach", Int. J. Prod. Res. Vol. 28, No. 4, (1990) pp: 615-635.
58-Abdou, G., and Dutta, S., " An Integrated Approach to Facilities Layout Using Expert System", Int. J. Prod. Res. Vol. 28, No. 4, (1990), pp: 685-708.
59- Sirinaovakul, B., and Thajchayapong, P. , " A Knowledge Base to Assist a Heuristic Search Approach to Facility Layout", Int. J. Prod. Res. Vol. 32, No. 1, (1994) pp:141-160.
60-Harraz, N., "A Knowledge-Based Decision Support System for Facility Layout", Msc. Thesis, Alexandria University, (1997).
61- Cox, e., "The Fuzzy System Handbook", AP., (1994).
62-Quantrille, T.E. and Liu, A.A . "Artificial Intelligence in Chemical Engineering" Academic Press, (1991).
63-Evans, G., Wilhelm, M., and Karwowski, W., " A Layout Design Heuristic Employing the Theory of Fuzzy Sets", Int. J. Prod. Res. Vol. 25, No. 10, (1987), pp: 1431 -1450.
64-Raoot, A., and Rakshit, A., " A Linguistic Pattern Approach for Multiple Criteria Facility Layout Problem", Int. J. Prod. Res. Vol. 31, No. 1, (1993), pp: 203-222.
65-Dweiri, F., and Meier, F., " Application of Fuzzy Decision-Making in Facilities Layout Planning", Int. J. Prod. Res. Vol. 34, No. 11, (1996), pp: 3207-3225.
66-Whyte, T. and Wilhelm, M. R., " Facility Layout Design Using Fuzzy Linguistic Variables and Fractals", unpublished Ph.D. dissertation, University of Louisville, Kentucky, USA, (1999).
67-McCulloch, W., and Pitts, W., "Artificial Neural Networks Technology", Technical Report, Data and Analysis Center for Software (DACS), NY, USA, (1992).
68-Schalkoff, R.J., "Artificial Neural networks", McGraw-Hill, (1997).
69-Tsuchiya, K., Bharitkar, S., and Takefuji, Y., "A Neural Network Approach to Facility Layout Problems" EJOR, Vol. 89, (1996), pp: 556-563.
70-Coly, D.A. , "An Introduction to Genetic Algorithms for Scientists and Engineers" World Scientific, (1999).
71-Pardalos, P.M., Pitsoulis, L.S., Mavridou, T.D., and Resende, M.G.C., "A Parallel Search for Combinatorial Optimization: Genetic Algorithms, Simulated Annealing, Tabu Search and GRASP" Lecture Notes in Computer Science, 980, Springer-Verlag, (1995), pp: 317-331.
72-Davis, L. ed., "Handbook of Genetic Algorithms", Van Nostrand Reinhold. (1991).
73-Tam, K., " Genetic Algorithms, Function Optimization, and Facility Layout Design", EJOR, Vol. 63, (1992), pp: 322-346.
74-Chan, K. and Tansri, H., " A Study of Genetic Crossover Operations on the Facility Layout Problem", Computers and Industrial Engineering Vol. 26, No. 3, (1994) PP: 537 -550.
75-Conway, D.G. and Venkataramanan, M.A., " Genetic Search and the Dynamic Facility Layout Problem", Computers and Operation Research, Vol. 21, No. 8, (1994) pp: 955 -960.
76-Sulung and Chan, K. C., " Design of 2-Dimensional Crossover Operators for the Facilities Layout Problem", Proceedings of Artificial Neural Networks in Engineering, Vol. 6, (1996), pp: 373-378.

77-Cheng, R., Gen, M., and Tosawa, T., " Genetic Algorithms For Designing Loop Layout manufacturing Systems", Computers and Industrial Engineering, Vol. 31, No. ¾, (1996), pp: 587-591.
78-Kochhar, J. S., Foster, B. T., and Heragu, S. S., " HOPE: A Genetic Algorithm for the Unequal Area Facility Layout Problem", Computers Ops Res., Vol. 25, No. 7/8, (1998), pp: 583-594.
79-Kochhar, J. S., and Heragu, S. S., " MULTI- HOPE : A Tool for Multiple Floor Layout Problems", Int. J. Prod. Res., Vol. 36, No. 12, (1998), pp: 3421-3435.
80-Hamamoto, S., Yih, Y., and Salvendy, G., " Development and Validation of Genetic Algorithm-Based Facility Layout: A Case Study in the Pharmaceutical Industry", Int. J. Prod. Res., Vol. 37, No. 4, (1999), pp: 749-768.
81-Pham, D. and Onder, H., " A Knowledge-Based System for Optimizing Workplace Layouts Using a Genetic Algorithm", Ergonomics, Vol. 35, No. 12, (1992) pp: 1479-1487.
82-Cheng, R., Gen, M., and Tozawa, T., " Genetic Search For Facility Layout Design Under Inter-lows Uncertainty", Proceedings of IEEE Int. Conf. on Evolutionary Computation, Part 1, (1995), pp: 400-405.
83-Badiru, A. B.,Arif, A. " FLEXPERT: Facility Layout Expert System Using Fuzzy Linguistic Linguistic Relationship Codes", IIE Transactions, Vol. 28, No. 4,(1996), pp: 295-308.
84-Chung, Y. K., " Application of a Cascade BAM Neural Expert System to Conceptual Design for Facility Layout", Computers and Mathematics with Applications, 37, (1999), pp: 95-110.