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Simulation Methodology for Facility Layout Problems

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--Abstract--

Abstract- *In this paper an attempt is made to present a state-of the- art review of papers on simulation methodology for facility layout problems. This paper aims to deal with the current and future trends of research on simulation methodology for facility layout problems based on previous research including exact, heuristic, meta-heuristic and development of various Intelligent Hybrid Systems approach. New developments of various techniques provide a perspective of the future research in facility layout problems. Facility layout problem is one of the truly difficult ill-structured, multicritria and 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. The weakness of some techniques can be offset by the strengths of other techniques for that intelligent hybrid systems are promising solver tools for intelligent systems*

Keywords- *Facility planning, intelligent techniques, intelligent Hybrid Systems.*

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I. Introduction

Future manufacturing system needs to be dynamically reconfigurable to produce customized products in small batch with fast turn-around times in cost-efficient manner. The capability to reconfigure an existing manufacturing system is a key factor to maintain competitiveness in manufacturing business environment [1]. Taha *et al* [2] suggested that in order to be successful in today's competitive manufacturing environment, managers have to look for new approaches to facilities planning. According to Balakrishnan *et al* [1], it was estimated that over $250 billion is spent annually in the United States on facilities planning and re-planning. Further, between 20%- 50% of the total costs within manufacturing are related to material handling and effective facility planning can reduce these costs 10-30%. For FLP, the most common objective used in mathematical models is to minimize the materials handling cost, which is a quantitative factor. Qualitative factors such as plant safety, flexibility of layout for future design changes, noise and aesthetics can also be considered. They must be carefully considered in the context of the FLP. This paper discusses on previous study and significant finding in solution methodology for facility planning and design. The FLP is a well studied combinatorial optimization problem which arises in a variety of problems such as printed circuit board design; layout design of hospitals, schools, and airports; backboard wiring problems; typewriters; warehouses; hydraulic turbine design; etc. The focus of this review work is on the facility layout of industrial (manufacturing) plants, which is concerned with finding the most efficient arrangement of 'n' indivisible facilities in 'n' locations. Minimizing the material handling cost is the most considered objective but Mecklenburgh [4] and Francis et al. [5] gave qualitative as well as quantitative objectives for FLP. Reduced material movement [6, 7] lowers work-in-process levels and throughput times, less product damage, simplified material control and scheduling, and less overall congestion. Hence, when minimizing material handling cost, other objectives are achieved simultaneously. The output of the FLP is a block layout that specifies the relative location of each department. Detailed layout of a department can also be obtained later by specifying aisle structure and input/output point locations which may include flow line and machine layout problems.

1. Solution methodology

The various solution methodologies, e.g. exact procedures, heuristics and meta-heuristics available to solve facility layout problems optimally or near to optimal, are discussed in detail. Exact procedures that can give optimal solutions to facility layout problems are discussed in following Sections.

a) Exact procedure

Branch and bound methods are used to find an optimum solution of quadratic assignment (QAP) formulated FLP because QAP involves only binary variables. Only optimal solutions up to a problem size of 16 are reported in literature [57]. Beyond n=16 it becomes intractable for a computer to solve it and, consequently, even a powerful computer cannot handle a large instance of the problem.

b) Heuristics

A comprehensive investigation of the FLP literature includes examining heuristics. Heuristic algorithms can be classified as construction type algorithms where a solution is constructed from scratch and improvement type algorithms where an initial solution is improved. Construction based methods are considered to be the simplest and oldest heuristic approaches to solve the QAP from a conceptual and implementation point of view, but the quality of solutions produced by the construction method is generally not satisfactory. Improvements based methods start with a feasible solution and try to improve it by interchanges of single assignments. Improvement methods can easily be combined with construction methods. CRAFT [8] is a popular improvement algorithm that uses pair wise interchange. Surveys of a few well known heuristics which are popular as layout software are provided in Table 1 along with the algorithm used. These heuristics are classified as adjacency and distance based algorithms. For instance, MATCH [9] and SPIRAL [10] are adjacency based while CRAFT [8], SHAPE [11], LOGIC [12], MULTIPLE [13], and FLEX-BAY [14] are distance based algorithms (descriptions are not provided but interested readers can refer to the cited papers).

c) Meta-heuristics

Various meta-heuristics such as SA, GA, and ant colony are currently used to approximate the solution of very large FLP. The SA technique originates from the theory of statistical mechanics and is based upon the analogy between the annealing of solids and solving optimization problems. Burkard and Rendl [15] derived SA for QAP. GA gained more attention during the last decade than any other evolutionary computation algorithms; it utilizes a binary coding of individuals as fixed-length strings over the alphabet {0, 1}. GA iteratively search the global optimum, without exhausting the solution space, in a parallel process starting from a small set of feasible solutions (population) and generating the new solutions in some random fashion. Performance of GA is problem dependent because the parameter setting and representation scheme depends on the nature of the problem. Tavakkoli- Moghaddam and Shayan [16] analyzed the suitability of genetic operator for solving FLP. Tabu search (TS) is an iterative procedure designed to solve optimization problems. Helm and Hadley [17] applied TS to solve FLP. The method is still actively researched, and is continuing to evolve and improve. Recently, a few papers have appeared where an ant colony algorithm has been attempted to solve large FLP. Talbi et al. [18] applied ant colony to solve QAP.

d) Intelligent techniques

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. As a matter of fact, Facility layout problem can be considered one of the truly difficult ill-structured, multi- criteria 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

Expert Systems- Expert systems are considered as one of a conceptual breakthrough in artificial intelligence (AI) field. 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 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.

Fuzzy Systems- 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].

i) Selection the set of both input/output linguistic variables that are natural to the application and whose crisp Values are available.
ii) Determination of membership functions for all linguistic variables labels.
iii) 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.
iv) Development of a knowledge base of fuzzy rules, fuzzy inference strategy, system prototyping, testing, and documentation.

II. Neural Networks

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 (1992) on how neurons might work. They modeled a simple neural network with electrical circuit. 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. The main features that make ANNs advantages over computational techniques, as mentioned in 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 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. A survey of papers where these methodologies have been applied to solve FLP is given in Table 1.

III. Genetic Algorithms

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. 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 as

Input: a problem instance
Output: a sub-optimal solution

i) t=0, initialize P_t, and evaluate the fitness of the individuals in P_t
  a. While (terminating condition is not satisfied) do
  a- t=t+1
  b- Select P_t, recombine P_t, and evaluate P_t
ii) 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.

e) Intelligent Hybrid Systems approach

There is emerging research into applying meta-heuristic such as SA, GA and tabu search to solve large FLP. But, the final result depends on the initial solution (or population) taken. Therefore, more research is required to develop good heuristic to generate good initial feasible solutions. 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. Pham and Onder [19] 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 for solving complex ergonomic design problems. Cheng et al [20] 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 way to build powerful knowledge-based systems 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. Badiru and Arif [21] 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. Chunag [22] 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. In order to response effectively to the changes in product mix and volume, manufacturing facility need to be changed frequently,Guxin W.[46] found the facility layout design becomes critical , he proposed a simulation methodology (GA), that automatically guide the system towards better solutions. Simulation models are used to evaluate the performance of layout schemes, the results of evaluation are returned to GA to be utilized in selection in the next generation of candidate facility layout scheme to be evaluated. This process continues until a satisfactory solution is obtained. A. Hadi-Vencheh [52] .it is crucial to design an efficient FLD problem in a production factory. Ignoring the significant criteria (especially, the qualitative criteria which are not easily stateable in the quantitative measures form) in design time will certainly result in increasing the costs, prices and ultimately decreasing the products' sale. In this study, using the SVFJ approach, we transformed the subjectivity subjects of designers (in linguistic variables form) against qualitative criteria which are stated by assessing printed FLPs in program output, to quantitative measures. These judgments occurred via erecting the distinct sessions in order to do not have any prejudice about other. Also we introduced the other quantitative criteria in addition to TCHM called construction cost, which is considered due to difference in the width walls of FLPs. Then, we ranked 10 FLPs regarding to these five criteria via a NLP model. Here, it is significant to mention some points: first, in this study, we just considered the main sections (departments) to rank while each of those may include other subsections that were not taken into account in our study (e.g., production section may include office sections, work in progress, etc.). Second, by changing the initial sequence which designers used as input FLP in CRAFT, it is possible to produce other FLPs differed from FLPs presented. Ultimately, owning to the fact that the performance measures of qualitative criteria achieved based on subjectivity judgments, these severely depend on such judgments and sometimes can result in inconsistent on behalf of designers. But despite all these limitations, the proposed integrated SVFJ–NLP approach ranks the FLPs, is simple, efficient and applicable for any number of FLPs under any number of the qualitative and quantitative criteria. A tendency of using Metaheuristic [53]such as Genetic Algorithm (GA), Simulated annealing(SA, Ant colony optimization(ACO) and particle sworn optimization (PCO) with a trend towards multi objective approaches to layout and material handling system.

Table no. 1 Survey of Papers for solution methodology for facility layout problems

Reference	**Year**	**Solution Methodology**
Azadivar and Wang[23]	2000	GA and simulation algorithm
Ahuja [24]	2000	Genetic algorithm
Helm and Hadley [25]	2000	Tabu-search based
Al-Hakim [26]	2001	Maximally planer graph
Wu and Appleton [27]	2002	Genetic algorithm
Knowles and Corne [28]	2002	Multi-obj. approach
Lee, Han and Roh [29]	2003	GA, Dijkstra algorithm
Balakrishnan et al. [30]	2003	GA and SA
Castillo and Peters [31]	2003	Extended distance based
El-Baz, M. A.[32]	2004	Genetic algorithm
Chen, C. W., & Sha, D. Y.[33]	2005	Heuristic approach
Deb, S. K., & Bhattacharyya, B.[34]	2005	Fuzzy theory
Lee, K. Y., Roh, M. I.,&Jeong, H. S.[35]	2005	Genetic algorithm
Wang, M. J., Hu, M. H., & Ku, M. H.[36]	2005	Genetic algorithm
K.Y. Lee, M.I. Rohb, and H.S. Jeong[37]	2005	Genetic algorithm
Ming-Jaan Wang, Michael H. Hu, [38]	2005	Genetic algorithm
Arostegui et al[39]	2006	Tabu Search (TS), SA, and GA
Aiello, G., Enea, M., & Galante, G[40]	2006	genetic search algorithm and Electre method
McKendall, A. R., & Shang, J.[41]	2006	Hybrid ant systems
McKendall, A. Shang, J., & Kuppusamy, S.[42]	2006	simulated annealing (SA)
Nearchou, A. C.[43]	2006	Meta-heuristics
Xiaodan et al[44]	2007	concurrent approach, hierarchical genetic algorithm
Hong Zhang, and Jia Yuan Wang[45]	2008	Particle Swarm Optimization
Guoxin Wang[46]	2008	A simulation optimization approach for facility layout problem.
Ashwani Dhingra[47]	2009	Hybrid Genetic algorithm
Scholz, Daniel Petrick, Anita Domschke,[48]	2009	A Slicing Tree and Tabu Search
Nurul Nadia Nordin, Zaitul Marlizawati [49]	2009	Hybrid Heuristic
Komarudin, Kuan Yew Wong[50]	2010	Ant System
Alan R. McKendall Jr., Artak Hakobyan[51]	2010	Heuristic approach
Kundu.A. and Dan.P.K.[54]	2012	Metaheuristic in facility layout problem; Current and future direction.

IV. CONCLUSION

In conclusion, it is found that analysis of facility design such as layout and material handling system is very important in a manufacturing industry. Proper analysis of existing layout design could improve the performance of production line. It could decrease bottleneck rate, minimize material handling cost, reduces idle time, raise the efficiency and utilization of labour, equipment and space. Heuristic methods such as Tabu Search (TS), Simulated Annealing (SA), and Genetic Algorithms (GA) etc. are common tools in optimization. Limitations of those solution methods are time consuming and weakness of some techniques. 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.

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