Analysis of Unequal Areas Facility Layout Problems

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Abstract

The facility layout design has been regarded as the key to improve plant productivity, which are relevant to both manufacturing problems; various optimization approaches for small problems and heuristic approaches for the larger problems have been proposed to elucidate the problem. Unequal area facility layout problems comprise a class of extremely difficult and widely applicable optimization problems, arising in many diverse areas. There are many variations on the basic formulation, involving alternative objective functions, side constraints, distance metrics, cost measures, and facility shapes. Various techniques were applied after finding the solution through traditional methods to get much improved optimum solutions. Different heuristics were used to solve the unequal area facility layout problems. Multi-objective approaches are the norm and developing facility layout software using meta-heuristics such as simulated annealing (SA), genetic algorithm (GA), ant colony algorithm (ACO), and concurrent engineering is prevailing nowadays. Sometimes hybrid approaches were used by applying combination of above techniques i.e. combining high level genetic algorithm with simulated annealing or genetic algorithm followed by simulation techniques to get the better solutions. Application of these facility lay out designs includes construction sites, manufacturing industry and service industries.and service sectors. Facility Layout Problems (FLPs) are known to be NP-hard

Keywords—Facility layout, unequal area , Hybrid methods , Genetic Algorithm, Automated layout Manufacturing Industries, construction sites.

1.INTRODUCTION

The static facility layout problem (SFLP) is a well-researched problem of finding positions of departments on the plant floor such that departments do not overlap while some objective is optimized. The most commonly used objective is minimizing material handling cost (i.e., minimizing the sum of the product of the flow of materials, distance, and transportation cost per unit per distance unit for each pair of departments). When material flows between departments change during the planning horizon, the problem becomes the dynamic facility layout problem (DFLP).

A solution to the FLP is a block layout that specifies the relative location and the dimensions of each department. Once a block layout has been achieved, a detailed layout can be designed which specifies department locations, aisle structures and input/output point locations [3, 6, 7]. Two types of approaches for finding provably optimal solutions for the FLP have been proposed in the literature. The first type are graph-theoretic approaches that assume that the desirability of locating each pair of facilities adjacent to each other is known. Initially, the area and shape of the departments are ignored, and each department is simply represented by a node in a graph. Adjacency relationships between departments can now be represented by arcs connecting the corresponding nodes in the graph. The objective is then to construct a graph that maximizes the weight on the adjacencies between nodes. We refer the reader to [4] for more details. The second type are mathematical programming formulations with objective functions based on an appropriately weighted sum of centroid-to-centroid distances between departments. Exact mixed integer programming formulations were proposed for the above type was shown in [8,9].

2. UNEQUAL AREA LAYOUTS

The unequal-areas facility layout problem (FLP) is concerned with finding the optimal arrangement of a given number of non-overlapping indivisible departments with unequal area requirements within a facility. The block layout design problem with unequal areas, which was originally formulated by Armour and Buffa in the early 1960s, is a fundamental optimization problem encountered in many manufacturing and service organizations. Different methods were discussed for solving unequal area problems in Literature. These methods are summarized under the various topics to have a understanding of Unequal area problem.

2.1 Tree structure Model

The facility layout design has been regarded as the key to improve plant productivity, which are relevant to both manufacturing and service sectors. A tree structure model has been proposed for representing the unequal-area facility layout by[10]. Each facility has a different rectangular shape specified by its area and aspect ratio. In this layout problem, based on the assumption that the shop floor has enough space for laying out the facilities, no constraint is considered for a shop floor. Objectives are minimizing total part movement between facilities and total rectangular layout area where all facilities and dead spaces are enclosed. Using the genetic code corresponding to two kinds of information, facility sequence and branching positions in the tree structure model, a genetic algorithm has been applied for finding non-dominated solutions in the two-objective layout problem. [10] used three kinds of crossover (PMX, OX, CX) for the former part of the chromosome and one-point crossover for the latter part. Two kinds of layout problems have been tested by the proposed method. The results demonstrated that the presented algorithm was able to find good solutions in enough short time.

2.2 Genetic Search

[23] used Genetic search for solving construction site-level unequal-area facility layout problems. A construction site represents a conflux of concerns, constantly calling for a broad and multi-criteria approach to solving problems related to site planning and design. As an important part of site planning and design, the objective of site-level facility layout is to allocate appropriate locations and areas for accommodating temporary site-level facilities such as warehouses, job offices, workshops and batch plants. Depending on the size, location and nature of the project, the required temporary facilities may vary. The layout of facilities can influence on the production time and cost in projects. [23]described a construction site-level facility layout problem as allocating a set of predetermined facilities into a set of predetermined places, while satisfying layout constraints and requirements. A genetic algorithm system, which is a computational model of Darwinian evolution theory, was employed to solve the facilities layout problem. A case study was presented to demonstrate the efficiency of the genetic algorithm system in solving the construction site-level facility layout problems

2.3 Hybrid Method

[12] presented the solution of the unequal area problem by hybridizing the meta-heuristic methods i.e. Genetic Algorithm (GA) and Simulated Annealing (SA). (SA) is a related global optimization technique that traverses the search space by testing random mutations on an individual solution. A mutation that increases fitness is always accepted. A mutation that lowers fitness is accepted probabilistically based on the difference in fitness and a decreasing temperature parameter. In SA parlance, one speaks of seeking the lowest energy instead of the maximum fitness. SA can also be used within a standard GA algorithm by starting with a relatively high rate of mutation and decreasing it over time along a given schedule.

[12] could be used in future as a reference for those researchers interested in tackling this challenging unequal facility layout problem. A mathematical model was developed for the unequal size facility layout problem with fixed flow between departments. The orientations of the departments with various sizes were considered to minimize the distance traveled by people, material, and other supporting services in the safest and most effective manner. Some of the constraints considered in the modeling were the restricted areas, reserved department locations, and also the irregularity of the shapes of manufacturing layout. This paper has also presented the use of hybrid algorithm (GA - SA) as a general methodology to solve the facility layout problem under consideration.

A hybrid optimization approach was presented in [21] for the layout design of unequal-area facilities. Simulated annealing was used to optimize a randomly generated initial placement on an “extended plane” considering the unequal-area facilities enclosed in magnified envelop blocks. An analytical method was then applied to obtain the optimum placement of each envelop block in the direction of steepest descent. Stepwise reduction of the sizes of the envelop blocks allowed controlled convergence in a multi-phase optimization process. The presented test problems include two large size benchmark problems of 50 and 100 facilities of unequal areas. The results indicated a significant improvement over previously published techniques for unequal-area facilities and could yield solutions of the same quality as obtained by PLANOPT, a general-purpose layout optimization program based on pseudo-exhaustive search.

2.4 Convex Optimization Framework

[13] presented a convex-optimization-based framework for efficiently finding competitive solutions for this problem. The framework is based on the combination of two mathematical programming models. The first model is a convex relaxation of the layout problem that establishes the relative position of the departments within the facility, and the second model uses semi-definite optimization to determine the final layout. Aspect ratio constraints, frequently used in facility layout methods to restrict the occurrence of overly long and narrow departments

in the computed layouts, are taken into account by both models. It suggested that using ellipsoids instead of circles to approximate the initial positions of departments could provide better results and Ellipsoids would likely provide more realistic estimations of department positions, since departments in real-world applications are not square-shaped. Further work also included adjusting the φ (the parameter that can control what the desired smallest length or width should be in each department's layout) and potentially using a different value φi for each department. Finally, different combinations of first stage and second stage models from past papers tested to get the over all results.

2.5 Tabu search Method

Tabu search (TS) is similar to simulated annealing in that both traverse the solution space by testing mutations of an individual solution. While simulated annealing generates only one mutated solution, tabu search generates many mutated solutions and moves to the solution with the lowest energy of those generated. In order to prevent cycling and encourage greater movement through the solution space, a tabu list is maintained of partial or complete solutions. It is forbidden to move to a solution that contains elements of the tabu list, which is updated as the solution traverses the solution space.

[14] discussed a slicing tree based tabu search heuristic for the rectangular, continual plane facility layout problem by incorporation of facilities with unequal areas and integrated the possibility to specify various requirements regarding (rectangular) shape and dimensions of each individual facility by using bounding curves which made possible to solve problems containing facilities of fixed and facilities of flexible shapes at the same time. This paper presented a procedure that calculated the layout corresponding to a given slicing tree on the basis of bounding curves and integrated the tabu search to find the better results. [19] proposed a heuristics for the dynamic facility layout problem with unequal-area departments. The solution is improved using a tabu search heuristic. The heuristics were tested on some instances from the DFLP and static facility layout problem (SFLP) literature. The results obtained demonstrated the effectiveness of the heuristics.

2.6 Genetic Algorithm

[15] presented a genetic algorithm-based model for facility layout problems with unequal departmental areas and different geometric shape constraints. Gene structures of the genetic algorithm are used to represent layout of departments. The algorithm involved deriving an initial assignment of departments to the given floor plan and then, possibly, improving the solution quality through genetic algorithm mechanisms (i.e., exchange parts of layout). Since genetic algorithm is parameter sensitive, the experiments indicated that crossover type, mutation type, mutation probability, and population size which are the main parameters that designers need to consider while designing facility layout with genetic algorithm. Guidelines for such parameters were also given.

[11] presented a heuristic search methodology, based on genetic algorithms (GA), for unequal area layout. this methodology was applied to several standard test problems from the literature, and was showed that the GA method gave solutions which were much better than the best previously reported solutions.[11] used penalty-directed search to find very good solutions to problems with difficult-to-satisfy side constraints, and to perform multi-criterion optimization with respect to cost measures that have been considered incommensurable in the past. The methodology presented in [11] is not intrinsically restricted to layout problems, but could be extended to other hard combinatorial problems. The GA/penalty method's ability to find improved solutions to known problems, together with the ability to address problems with ill-behaved cost functions, multiple objectives, and/or side constraints, constitutes a significant contribution to the state of the art in facility layout. Furthermore, GA could be implemented to

take advantage of parallel hardware to an extent not possible for other heuristic optimization methods.

[18] outlined a GA based algorithm for solving the single-floor facility layout problem with departments of both equal and unequal sizes. The GA performance was evaluated using several test problems available in the literature. The results indicated that GA may provide a better alternative in a realistic environment where the objective is to find a number of “reasonably good” layouts. The implementation also provided the flexibility of having fixed departments and to interactively modify the layouts produced.

[24] gave a solution to the unequal area facilities layout problem by genetic algorithm. The majority of the issued facilities layout problems (FLPs) minimize the material handling cost and ignore other factors, such as area utilization, department shape and site shape size. These factors, however, might influence greatly the objective function and should give consideration. The research range of [24] was focused on the unequal areas department facilities layout problem, and implement analysis of variance (ANOVA) of statistics to find out the best site size of layout by genetic algorithm. The proposed module took the minimum total layout cost (TLC) into account. TLC was an objective function combining material flow factor cost (MFFC), shape ratio factor (SRF) and area utilization factor (AUF). In addition, a rule-based of expert system was implemented to create space-filling curve for connecting each unequal area department to be continuously placed without disjoint (partition). In this manner, there was no gap between each unequal area department. The experimental results showed that the proposed approach is more feasible in dealing with the facilities layout problems in the real world.

2.7 Swarm Optimisation

Layout of temporary facilities on a construction site is essential to enhancing productivity and safety, and is a complex issue due to the unique nature of construction. [16] proposed a particle swarm optimization (PSO)-based methodology to solve the construction site unequal-area facility layout problem. A priority-based particle representation of the candidate solutions to the layout problem was proposed. The particle-represented solution in terms of priorities should be transformed to the specific layout plan with consideration of non-overlap and geometric constraints. In addition, a modified solution space boundary handling approach was proposed for controlling particle updating with regard to the priority value range. Computational experiments were carried out to justify the efficiency of the proposed method and to investigate its underlying performances. This paper claimed to provide an alternative and effective means for solving the construction site unequal-area layout problem by utilizing the PSO algorithm.

2.8 Space Partitioning

[17] proposed a space partitioning method for facility layout problems with shape constraints A heuristic algorithm was developed for the problems with the objective of minimizing the sum of rectilinear distances weighted by flow amounts between the facilities. The suggested algorithm was a simulated annealing algorithm in which a solution is encoded as a matrix that has information about relative locations of the facilities on the floor. A block layout was constructed by partitioning the floor into a set of rectangular blocks according to the information while satisfying the areas of the facilities. [17] suggested three methods for the partitioning.

2.9 Ant System

Ant Colony Optimization (ACO) is a young metaheuristic algorithm which has shown promising results in solving many optimization problems. To date, a formal ACO-based metaheuristic has not been applied for solving Unequal Area Facility Layout Problems (UA-FLPs). [20] proposed an Ant System (AS) (one of the ACO variants) to solve them. As a discrete optimization algorithm, the proposed algorithm used slicing tree representation to easily represent the problems without too restricting the solution space. It used several types of local search to improve its search performance. It is then tested using several case problems with different size and setting. Overall, the proposed algorithm showed encouraging results in solving UA-FLPs.

2.10 MILP and MINLP optimization methods

[22]presented a new modelling framework for effectively finding global optimal solutions for the block layout design problem with unequal areas. The most fundamental aspect of the framework consists of an exact representation of the underlying area restrictions. Our computational results consistently yield optimal solutions on several well-known test problems from the published literature. Furthermore, different mixed-integer linear and mixed-integer nonlinear optimization methods are compared. Our study indicates that the new modeling framework together with simple constraints to avoid symmetric layout solutions can be successfully used to find optimal layout solutions; therefore, seriously challenging other optimization methods on this important class of hard, fundamental problems. The new modeling framework may easily be applied in the context of the process plant layout and piping design problems.

2.11 automated layout

[25] generated Automated layout of facilities of unequal areas. Common to the analytical techniques for automated layout of rectangular facilities of unequal areas is the problem of too rapid movement of the representative blocks to form a cluster. This phenomenon made the converged designs too dependent on the initial layout and the order of movement of the blocks. A concept of “controlled convergence” was introduced to solve this problem. Convergence is controlled by carrying out the optimization with the “envelop blocks” of sizes much larger than the actual facilities. The sizes of the envelop blocks were gradually reduced to the actual sizes of the facilities through the optimization cycles. Test results were given to demonstrate the effectiveness of the presented technique.

2.12 Mixed Integer Programming method

[26] proposed an ε-accurate model for optimal unequal-area block layout design by developing a mixed-integer linear programming model for the block layout design problem with unequal areas that satisfies the area requirements with a given accuracy. The basic aspect of the model consists of an ε-accurate representation of the underlying non-convex and hyperbolic area restrictions using cutting planes. The use of such a representation of the area restrictions gave way to solve several challenging test problems to optimality with a guarantee that the final area of each department was within an ε% error of the required area. Numerical results indicated that the proposed model seriously challenge other optimization approaches on this important class of hard, fundamental problems

2.13 Graph Theory method

[27] developed Graph theoretic heuristics for unequal-sized facility layout problem. It considered the unequal-sized facility layout problem with the objective of minimizing total transportation distance. The total transportation distance was defined as the sum of products of flow amounts and rectilinear distances between facilities, where flow amount represents the number of trips per time period between facilities. In the layout problem, it was assumed that shapes of facilities are not fixed and that there was no empty space between facilities in the layout. It proposed new graph theoretic heuristics for the problem. In the heuristics, an initial layout was obtained by constructing a planar adjacency graph and then the solution was improved by changing the adjacency graph (not the physical layout). Therefore, these heuristics did not need an initial layout in advance, and sizes and locations of facilities did not

have to be considered in the improvement procedure. Computational results showed that the proposed algorithms gave better solutions than those from CRAFT, which is one of the most popular algorithms for unequal-sized facility layout problems.

3. SUMMARY

The various techniques such as simulated annealing (SA), genetic algorithm (GA), ant colony algorithm (ACO), and concurrent engineering is prevailing nowadays. Sometimes hybrid approaches were used by applying combination of above techniques i.e. combining high level genetic algorithm with simulated annealing or genetic algorithm followed by simulation techniques to get the better solutions. Application of these facility lay out designs includes construction sites, manufacturing industry and service industries. Out of these techniques, most commonly used techniques were discussed briefly to highlight the growth in unequal area facility layout. There is a vast scope to improve the facility layout design to fulfill the dynamic needs of Manufacturing and construction industries.

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