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Facility layout by collision detection and force exertion heuristics

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ABSTRACT

Facility layout problem (FLP) considers the optimization of layout costs, primarily on the account of material handling costs. FLP can be solved via mathematical modelling, heuristic or metaheuristic approaches. This paper presents a novel heuristic approach for solving the unequal area FLP. Here, facilities are randomly generated points that exert forces on each other based on a relation matrix. In this setup, every point is a centroid of the respective facility shape and two heuristic methods are used to detect and consequently remove the collisions where the heuristic parameters influence the speed and quality of the final results. Furthermore, a graphic user interface (GUI) is designed to monitor performance of the proposed heuristic algorithm and modify its parameters while running if required. Finally, layout in higher dimensional space, facility rotation and future possible extensions are discussed.

1. Introduction

Facility layout problem (FLP) is defined as the problem of locating facilities in a limited area such that associated layout costs are minimized. Layout costs arise from various sources including material handling, time, and slack area. Meller et al. [1] described FLP for non-overlapping rectangular facilities where the flow-distance measure is optimized with respect to area constraints. Lee and Lee [2] considered FLP for unequal-area rectangular facilities in a given total space where material handling and slack area costs were optimized. Tompkins et al. [3] demonstrated significant reduction in the costs via layout improvement. Material handling is the primary source of layout costs and forms the core of objective functions in FLP research. Additional sources to consider are safety, noise, flexibility and aesthetics [4,5].

Layout problems are complex and NP-hard, thus, increasing the computational load significantly when the problem size increases [6,7]. Many FLP reviews are published, a number of which are as follows: Kusiak and Heragu [8] offered a comprehensive review of FLPs by distinguishing models of FLP as quadratic assignment, quadratic set covering, linear integer programming, mixed integer programming, and graph theoretic problems. They also distinguished branch and bound and cutting plane algorithms as optimal methods and ALDEP, CORELAP and PLANET as suboptimal solutions. In this study, deltahedron and wheel expansion algorithms were represented as graph-theoretic algorithms and solution quality and CPU time for twelve heuristic algorithms in eight test problems were compared. Meller and Gau [9] reviewed new trends in dynamic layout design, stochastic layout design, multi-criteria, robust, or flexible layout design and some special cases in 1990s. Drira et al. [10] offered a comprehensive FLP review, covering a wide spectrum of concepts ranging from its definitions, manufacturing systems, facility shapes, etc. to solution approaches, constraints, objectives, etc. Singh and Sharma [5] reviewed a list of FLP heuristics and metaheuristics including heuristics MATCH, SPIRAL, CRAFT and etc. and metaheuristics such as simulated annealing (SA), genetic algorithm (GA) and other approaches like fuzzy set theory. Table 1 lists facility layout packages in the review by Singh and Sharma.

The notion of unequal area facilities was first introduced in the famous CRAFT algorithm, but initial tendency towards unequal-area FLP (UAFLP) had earlier emerged in the 1990s. Related research efforts are as follows: Heragu and Kusiak [11] presented linear continuous and linear mixed integer with unequal facilities. Jajodia et al. [12] used SA to target inter-cell and intra-cell layout problems. Tam [13] introduced SA search in slicing trees that represent rectangular partitions. Imam and Mir [14] introduced envelope blocks for controlling convergence of optimization procedure. Tate and Smith [15] used GA with constraints on department shapes. In addition to SA and GA variants, ant colony optimization is also used for unequal-area FLP [16–18]. Moreover, recent studies considered the interaction between decision makers in the layout process. For instance, the interactive genetic algorithm proposed by García-Hernández et al. [19] is capable of gathering decision

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Table 1
Facility layout packages in the review by Singh and Sharma.

Reference	Package name
Dr. Gordan Armour	CRAFT
Seehof and Evans	ALDEP
Dr. Moore James	CORELAP
Michael P. Deisenroth	PLANET
Teichholz Eric	COMP2
Kaiman Lee	COMPROPLAN COMSBUL
Robert C. Lee	CORELAP8
Robert Dhillon	DOMINO
Teichholz Eric	GRASP
Dr. Johnson T.E.	IMAGE
Dr. Warnecke	KONUVER
Dr. Warnecke	LAYADAPT
Raimo Matto	LAYOPT
John S. Gero	LAYOUT
Dr. Love R.F.	LOVE
Dr. Warnecke	MUSTLAP2
Dr. Vollman Thomas	OFFICE
McRoberts K.	PLAN
Anderson David	PREP
Moucka Jan	RG and RR
Dr. Ritzman L.P.	RITZMAN
Dr. Warnecke	SISTLAPM
Prof. Spillers	SUMI
Hitchings G.	Terminal Sampling Procedure
Johnson	SPACECRAFT
Tompkins and Reed	COFAD
Hassan, Hogg and Smith	SHAPE
Banerjee et al.	QLAARP
Tam	LOGIC
Bozer, Meller, and Erlebacher	MULTIPLE
Tate and Smith	FLEX-BAY
Foulds and Robinson	DA (Adjacency Based)
Montreuil, Ratliff and Goetschalckx	MATCH (Adjacency Based)
Goetschalckx	SPIRAL (Adjacency Based)
Balkrishnan et al.	FACOPT

maker preferences. Aiello et al. [20] introduced non dominated ranking multi objective genetic algorithm and electre methods, which allows the decision maker to select choices based on limited solutions that passed the non-compensative criteria of multi objective optimization. Fujita et al. [21] discussed hierarchical layout design and proposed hybrid genetic algorithm to solve it.

Collision detection algorithms are widely used in physical simulations, robotics and CAD/CAM design. The collision phase has three components: collision detection, contact area determination, and collision response [22]. Collision detection is generally divided into priori and posteriori algorithms. Posteriori algorithms respond to object intersections whereas priori algorithms prevent the occurrence of collisions by predicting collisions and responding to them before collision occurrence. Collision detection is mainly implemented in 3D environments and contains hierarchical bounding volumes [23], spatial decomposition [24], and closest pairs computations via linear modelling [25]. Extensive research is conducted on collision detection algorithms. In this paper, collision response is targeted as a component in close relation with collision detection. Collision response is mainly seen as a relaxation of the initial solution. Simulation-based optimization is the term used by Gosavi [26] to distinguish models that cannot be expressed mathematically or in closed form expressions and optimization methods that require only values of the objective function at each state. Since the mathematical expression of the problem functions is not possible, the proposed algorithm is therefore a simulation-based relaxation algorithm that implicitly optimizes the problem. Furthermore, speed and quality of the results can be adjusted by appropriate algorithm parameter setting. Collision response aims at relaxing the initial solution but also optimizes the unused layout space. Hence, two measures of relaxation and slack space scores are utilized in the validation process.

The proposed algorithm of this paper is classified as a heuristic improvement algorithm since initial solutions are randomly generated and improved to yield the final sub-optimal solution. This algorithm consists of two stages: the initial solution is constructed in the first stage and the output of the first stage is improved in the second stage. The second stage of the algorithm is itself comprised of two different types of algorithms. These constituent algorithms are similar in that they both support unequal-area facilities, and their difference lies in the fact that one can accept any facility shape whereas the other only accepts rectangular facilities. Algorithms presented here are suitable for hierarchical layouts; therefore, it is recommended that space for facilities, operators and other requirements form workstations, workstations form departments and departments form the whole factory. These algorithms are tested for various runs of the algorithm with different parameter settings to acquire their running time in each case. A user interface is designed to monitor performance of the algorithm via dynamic modification of parameters while algorithms are running which is called FLCD (facility layout collision detection). The algorithm is then validated by permuting scores of facilities and slack spaces after obtaining the results. Permutations are generated by an implementation of Heap's algorithm [27]. This algorithm recursively divides permutations into smaller parts and outputs one permutation as it reaches the smallest part. Heap's algorithm is easy to implement and a review by Sedgewick suggests it as the fastest recursive algorithm available [28].

The FLP pitfalls which FLCD takes them into consideration are:

- Fast and straightforward: The algorithm should not hinder in infeasibility and should output a good quality, feasible solution in minimum possible time.
- Minimal complexity and easy to implement: Minimum number of parameters should be used. Furthermore, parameters should be derivable from facilities input data.
- Controllable and interactive: Decision maker should be able to see the process, interfere it and change parameters while the tradeoff between automation and preferences is satisfied.
- Flexible and improvable: The algorithm should avoid constructive procedures because constructive algorithms restrict optimality of total problem and succeeding facilities. Furthermore, the algorithm should be able to handle the facilities which might be added after the final layout is designed.

2. Method

A simple and fast heuristic method is hereby presented for locating central points in facilities together with a new core for the mesh and non-mesh heuristic algorithms such that construction of final layouts with respect to facility shapes is enabled. The relations matrix of departments or elements is a prerequisite for identification of material flow between pairs of facilities. This method was introduced by Muther [29] with values A, E, I, O, U and X in the form of a relations chart. However, in this research, relations can be either positive or negative in any scale (large values require revision in move step in the first stage of the algorithm i.e. force exertion) and the relations are described with sufficient accuracy in the form of symmetric matrices. Facility size is an additional requirement of the proposed heuristic algorithm. Additionally, mesh algorithm allows facility shape to have any form as defined by its vertices, but non-mesh algorithm requires facility shapes to be rectangular. Only approximate locations of the facility centres are required in the second stage for removing potential overlaps. A simple and fast method was therefore used instead of mathematical modelling for locating facility centres.