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An efficient multiple-stage mathematical programming method for advanced single and multi-floor facility layout problems

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ABSTRACT

Single floor facility layout problem (FLP) is related to finding the arrangement of a given number of departments within a facility; while in multi-floor FLP, the departments should be imbedded in some floors inside the facility. The significant influence of layout design on the effectiveness of any organization has turned FLP into an important issue. This paper presents a three- (two-) stage mathematical programming method to find competitive solutions for multi- (single-) floor problems. At the first stage, the departments are assigned to the floors through a mixed integer programming model (the single floor version does not require this stage). At the second stage, a nonlinear programming model is used to specify the relative position of the departments on each floor; and at the third stage, the final layouts within the floors are determined, through another nonlinear programming model. The multi-floor version is studied in the states in which the locations of the elevators are either formerly specified or not. Computational results show that this framework can find a wide variety of high quality layouts at competitive cost (up to 43% reduction) within a short amount of time for small and especially large size problems, compared to the existing methods in the literature. Also, the proposed method is flexible enough to accommodate the complicated and real-world problems, because of using mathematical programming model and solving it directly.

1. Introduction

A facility refers to anything that facilitates the work; in a manufacturing environment, it may be a workstation, a warehouse, a department, a machine tool, etc. Facility layout is the arrangement of all facilities needed for producing a product or delivering a service [1]. Facility layout problem has many applications in the real world, including layout design for manufacturing systems, hospitals, schools and airports, printed circuit board, backboard wiring problems, typewriters, warehouses, hydraulic turbine design, and so on [2–4]. A suitable structure for facility layout can be beneficial for any organization. For example, Francis et al. [5] stated that, in industrial environments, an appropriate layout could reduce total operating expenses by up to 15%.

Unequal-areas facility layout problem is concerned with determining the arrangement of a given number of departments within a facility (hereafter, a facility is the land space in which departments must be embedded), so that, under some

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constraints, a given qualitative or quantitative objective function would be optimized [6]. This objective function might be minimization of material handling costs [7,8], maximization of desirable relations between departments [9], or a combination of different objectives [10,11].

Most of the effort conducted in the field of FLP thus far are concerned with single–floor problems. But, nowadays, the rapid growth of industries and population, and consequently land shortage have led to an increase in land prices [12,13]. This challenge has necessitated the use of lands in multi-floor structures.

Quadratic assignment problem (QAP) is a restricted version of single floor FLP, in which the shapes of all departments are identical and fixed (see [14–17] for example). Considering computational effort, this problem is an NP-complete problem [6,18]. Therefore, other complicated problems with unequal-area departments and further constraints, such as the existence of a number of floors and elevators (for interaction between floors), are placed in the NP-complete class. This matter has engaged many researchers to present heuristic methods such as CRAFT, ALDEP, CORELAP [19], and planar graph technique [16], as well as to employ metaheuristic algorithms such as genetic algorithms, simulated-annealing algorithm, and tabu-search algorithm [20–23] for solving this problem. Nevertheless, these methods do not always provide good solutions.

Different models of multi-floor FLP are found in the literature, most of which have been examined in a deterministic state, and a limited numbers [24,25] have been studied in a dynamic state, as well. In terms of the objective function, most of the presented models have one objective, whereas the rest [12,26–28] are multi-objective. Also, some models have been restricted, such that they can only consider one elevator [29,30] and require fixed location elevators [28,30,31], equal area departments [29], as well as regular and fixed shapes for departments or/and floors [13,32]. In this respect, a limited number of models can accommodate the structure of aisles [28,33], two types of elevators [13], irregularly shaped departments and/or floors [12,34], location and number of elevators as decision variables [12,27], and also number of floors [26].

The methods offered for solving these problems operate in one or more stages. The single stage methods use the techniques, including mixed integer programming [13], heuristic exchange procedures [31], genetic algorithms [28,35], and simulated-annealing algorithm [36] to find a good layout. On the other hand, the multiple-stage methods often assign the departments to the floors at their first stage, and then determine the layout of the floors at the next stage(s). Indeed, multiple-stage methods may include one (or more) further stage(s) to obtain the final layout. The number and type of these stages may be different from one method to another. For example, one method first determines the block layout within each floor, and then tries to find the location of elevators [12,37]; while the other method only obtains the layout of departments, in one stage, by considering fixed located elevators [32]. Most of the methods that initially assign the departments to the floors use a mixed integer programming model [32,38,39] called FAF (floor assignment formulation) [38] for this purpose. However, other techniques like K-mean algorithm [29] have also been deployed. At the next stage(s), in order to find the detailed layout design, the techniques such as nonlinear programming [32], simulated-annealing algorithm [36–38], tabu-search algorithm [39], and heuristic exchange procedures [29] are employed.

Most of the frameworks presented in the literature often provide one solution (layout) for any problem, which may not be applicable. Furthermore, they mainly have many difficulties in computational time (and so, they are appropriate only for small size problems) and also the quality of the obtained layout.

In this paper, an exhaustive multiple-stage framework is presented for single- and multi-floor cases, in which the mathematical programming techniques are used to find a wide variety of high quality solutions with the lowest possible cost and within a short amount of time compared to the earlier frameworks in the literature. At the first stage (but only for multi-floor problems), a mixed integer linear programming is employed to assign departments to floors by minimizing vertical interaction cost between the departments. The second stage is a nonlinear programming model which establishes the relative position of departments on each floor using the same approach employed in [6], except that with some improvements (the model presented by Jankovits et al. [6] is entitled JLAV model, originated from the name of its authors, which was proposed for single-floor problems). At the third stage, using the solution obtained from the last stage, another nonlinear programming model is developed, in order to find the detailed layout of all floors simultaneously. The procedure for solving single-floor problems is similar to that of multi-floor problems, by this difference that it does not require stage one.

Other features of the proposed framework are its capability to accommodate the problems with fixed shapes and locations for departments, unequal-area and non-rectangular floors, as well as finding the location of elevators. In addition, the presented method is capable to incorporate the elevators with pre-determined and also not-pre-determined locations.

The rest of the paper is organized as follows. In Section 2, the background required for stage two of the presented method is provided. In Section 3, the method is proposed for single-floor cases. The extended version of single-floor to multi-floor cases is given in Section 4. Computational results that validate the strength and effectiveness of this method constitute Section 5. Finally, conclusions, managerial insights and potential directions for future work are discussed in Section 6.

2. Background to JLAV model

In this section, first, the single-floor FLP problem is explained (for solving of which many methods have been proposed in the literature). Afterward, JLAV model is described.