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A new mixed integer programming formulation for facility layout design using flexible bays

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Abstract

This paper presents a mixed-integer programming formulation to find optimal solutions for the block layout problem with unequal departmental areas arranged in flexible bays. The nonlinear department area constraints are modeled in a continuous plane without using any surrogate constraints. The formulation is extensively tested on problems from the literature.

Keywords: Facility design; Facility layout; Mixed integer programming; Flexible bay; Unequal areas

1. Introduction

In this paper, a new mixed-integer programming (MIP) formulation is proposed to solve the facility layout problem (FLP) with unequal departmental areas which is encountered in many manufacturing and service facilities. In its most general form, the FLP is defined as follows: Given N departments with known area requirements and interdepartmental material flow requirements, partition a planar area of size $W \times H$ into departments in order to minimize the total material handling cost. In general, the total material handling cost is expressed as

$$Z = \sum_{i=1}^{N} \sum_{j=i+1}^{N} c_{ij} f_{ij} d_{ij}, \tag{1}$$

where d_{ij} is the distance between departments i and j for a specified distance metric, f_{ij} is the amount of material flow, and c_{ij} is the material handling cost per unit flow per unit distance traveled between departments i and j. The constraints of the problem include satisfying the area requirements of the departments and the boundaries of the layout. In addition, restrictions on the shapes and locations of departments might be enforced because of practical concerns.

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The FLP has attracted extensive attention from industry and academia. Survey papers by Kusiak and Heragu [16] and Meller and Gau [21] summarize different modeling and solution approaches to the FLP. Due to the difficulty of the problem, however, the majority of work on the FLP has focused on heuristic approaches to find good solutions.

The formulation developed in this paper is based on the flexible bay structure (FBS), which is a continuous layout representation allowing the departments to be located only in parallel bays with varying widths (see Fig. 1(b)). The width of each bay depends on the total area of the departments in the bay. Bays are bounded by straight aisles on both sides, and departments are not allowed to span over multiple bays. Therefore, the FBS restricts possible layout configurations. However, it also has some desirable features. The bay boundaries form the basis of an aisle structure that facilitates the user transferring the block design into an actual facility design [1]. In addition, many manufacturing facility designs follow an implicit bay structure [19,27,31]. The FBS representation has been used as a design scheme in several heuristic approaches to the FLP [1,2,15,29]. Facility layout software such as BLOCKPLAN, developed by Donaghey and Pire [8], and SPIRAL, developed by Goetschalckx [10], also generate layouts based on the FBS. However, no exact solution approach or mathematical formulation has been reported in the literature for the FBS representation. Meller, in his related work [19] on layouts with bays, proposed a two-stage optimization approach where in the first stage, departments are assigned to bays to minimize the inter-bay material handling cost, and then in the second stage, departments are arranged within the bays to minimize the within-bay material handling cost. However, this two-stage approach cannot guarantee an optimal FBS solution for the overall facility. The formulation developed herein simultaneously assigns the departments to the bays and determines layouts within the bays considering departmental shape constraints; therefore, it is the first exact approach to find optimal FBS solutions.

2. MIP approaches to the FLP

As mentioned earlier, only a limited number of papers have addressed exact solution methods for the FLP. Exact solution methods based on MIP to date cannot solve large problems (more than nine departments) and/or they make assumptions, such as equal-sized departments and departments with fixed shapes and orientations, which are difficult to justify in practical cases. The quadratic assignment problem (QAP) introduced by Koopmans and Beckman [14] is the first mathematical formulation to optimally solve the FLP when all departments have the same area. In the QAP formulation, the facility is divided into N equal-sized grids, and each equal-sized department is assigned to exactly one grid and vice versa. An obvious drawback of the QAP formulation is the assumption of equal-sized departments. It is possible to model unequal area departments in the QAP formulation by breaking the departments into small grids with equal areas and not allowing the separation of grids of the same

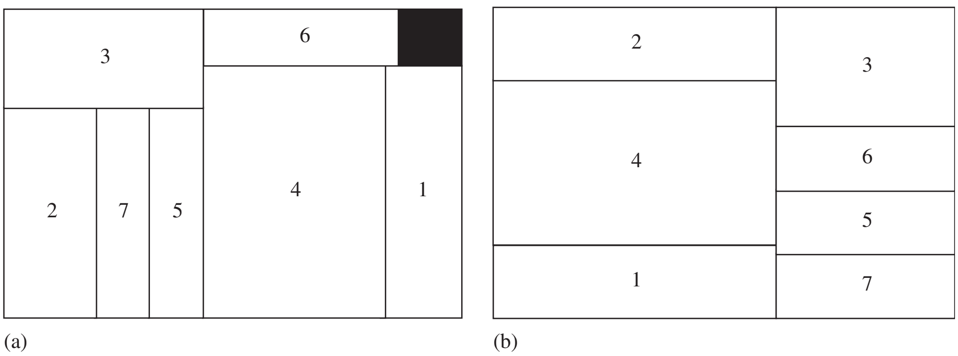

Fig. 1. Comparison of the optimal solutions for O71 found by: (a) Sherali et al. [28]; and (b) our formulation.