Computers & Industrial Engineering 102 (2016) 198–207

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Layout design problems with heterogeneous area constraints

Junjae Chae [a], Amelia C. Regan [b,*]

[a] School of Air Transport, Transportation and Logistics, Korea Aerospace University, South Korea
[b] Department of Computer Science, University of California at Irvine, USA

ARTICLE INFO

Article history:
Received 28 April 2016
Received in revised form 19 September 2016
Accepted 20 October 2016
Available online 22 October 2016

Keywords:
FLP (facility layout problem)
MIP (mixed integer programming)
Heterogeneous area constraint
Block layout design with unequal areas

ABSTRACT

The facility layout problem (FLP) is one of the design problems involving the assignment of facilities (e.g., machines, departments) to planar region (e.g., a plant), so as to achieve the objectives such as to minimize the cost of projected interaction between facilities or to maximize the closeness rating, etc. In this study, we deal with one of the FLP models that minimize the material handling cost between rectangular departments. Each department has an area restriction that specifies the total area that it must occupy while the specific lengths and widths are determined by the model. However, some department do not have flexibility and the dimension are predetermined. Thus, we proposed the to solve the layout design problem with two types of department. We call these constraints heterogeneous area constraints. The type A department, flexible length and width, and type B department, fixed length and width, are assigned to given floor space. Using a well-known data set which has been previously used by many other researchers, and modified version of the data aimed at testing our model, we show that the proposed model properly generates layout design for these two types of departments.

1. Introduction

The facility layout problem (FLP) is to find a non-overlapping arrangement of work areas (e.g., departments, workstations or service areas) within a given space with respect to a variety of objectives (e.g., minimizing total distance of material flow or maximizing the closeness effect). The departments or workstations are considered to be of rectangular shapes by many researchers, though others have assumed that the departments or workstations have irregular-shaped areas (Bock & Hoberg, 2007; Bukchin & Tzur, 2014). Irregularly shaped areas arise in application such as the design of shopping malls, zoos or ships, while factories, warehouses and cross-docking facilities typically have rectangular areas. For the objectives, minimizing the cost due to material flow between departments or workstations is common, but some research has been conducted for maximization problems or multi-objective problems. As mentioned, the FLP has been studied by many researchers and it has various problem types. For example, Kusiak and Heragu (1987), Meller and Gau (1996) provide detailed surveys of the different variants and solution approaches for the problem. Drira, Pierreval, and Hajri-Gabouj (2007) provides a tree representation for problem types, models, and approaches for facility layout problems. Other review papers focus on solution approaches tailored to specific aspects of layout problems (Levary & Kalchik, 1985; Liggett, 2000; Singh & Sharma, 2006; Tao, Wang, Qiao, & Tang, 2012).

The review of facility layout problems by Singh and Sharma (2006) and Drira et al. (2007) categorize two mathematical formulations for facility layout design: one is QAP (Quadratic Assignment Problem) for discrete formulations, and the other is MIP (Mixed Integer Programming) for continuous formulations. In this study, we deal with the continuous space of a facility assignment, MIP model, and have the objective of minimizing the total weighted distance of material flow in the space. The weighted distance between a paired departments is measured by the rectilinear distance multiplied by the number of trips between the centroids of the departments. Further, each department has an area restriction that specifies the total area that it must occupy, while the specific lengths and widths are determined by the model.

The facility layout problem is referred to as the block layout design problem when it deals with only rectangular blocks for departments. The problem has two main restrictions: the area requirement for the departments and floors, and the department location restrictions. The location restrictions are based on the continuous department positions in the given space and the area requirement for the department needs to handle the varying dimensions. The models and solution approaches for this block layout design problem has been studied by a number of researchers

* Corresponding author.
E-mail address: aregan@uci.edu (A.C. Regan).

http://dx.doi.org/10.1016/j.cie.2016.10.016
0360-8352/

and some of studies are focused on the direct solution of the optimization problem with unequal (non-uniform) area requirements. On the other hand, a model could be required to specify the orientation of the department in the case in which departments have fixed dimensions.

The models for this block layout design problem usually handle unequal area departments either with flexible dimension or with fixed dimension. In our research, we consider departments with unequal areas with changeable dimensions in the case of type "A" departments and fixed dimensions in the case of type "B" departments. To handle these two types of departments in a model, we need to analyze which part of variables and parameters can be used to represent both types of departments and which variables and parameters are necessarily used for specific types of departments. We follow the path of the modeling technique for direct solution of optimization of unequal area block layout design problems. In other word, the FLP model introduced by Sherali, Fraticelli, and Meller (2003) and Castillo and Westerlund (2005) is used to assign the type A departments. Then we provide a method to embed the different types of department restrictions, type B, into the model. Several methods to represent the type B department are evaluated and one of the methods is selected to use for embedding into the FLP model for type A department.

The FLP model for type A department presented by Sherali et al. (2003) and Castillo and Westerlund (2005) uses the linearization technique for non-linear department area constraints which is represented by the horizontal length multiplied by the vertical length. Thus this model has an area feasibility issue if there is no tolerance of restrictions for maximum aspect ratio of department. That means the layout configuration generated by the model could become infeasible when the underestimated department is expanded to its intended size. The chance that the model is feasible is increased when the model includes the type B department because of inflexibility of the department area. We test the feasibility of the layout configuration of the given problem set and show the possible number of linear segments of non-linear area constraint to have a feasible layout. Additional tests were done for relaxation on floor space to see the impact of area compactness on feasibility. Specifically, a larger problem set was tested to check the applicability of this relaxation. More details of the problem are explained in Section 2 and the background and the motivation for our research is also discussed in that Section. The modeling procedure and the methodology including heterogeneous department types in a single model are presented in Section 3, and the results generated by the proposed model are discussed in Section 4. In the last Section, the conclusion and directions for future research are provided.

2. Background

Most facility layout research resorts to developing heuristic solution methods since these problems are very difficult to solve optimally. Various solution approaches have been developed to solve these layout problems and several review papers present summaries of these (Drira et al., 2007; Kusiak & Heragu, 1987; Levary & Kalchik, 1985; Meller & Gau, 1996; Singh & Sharma, 2006). Adding the unequal area requirements with varying dimensions makes the problem even more difficult to solve. However, there have been attempts to solve the problem through traditional modeling and optimization techniques. Several studies present improved techniques to model problems in this category (Castillo & Westerlund, 2005; Lacksonen, 1994; Meller, Narayanan, & Vance, 1999; Montreuil, 1990; Sherali et al., 2003). These research efforts provide methods to linearize the unequal area constraint so that a mixed integer linear programming (MILP) model can be solved. The models in those papers assume that all the departments have variable width and length dimensions. However, as discussed in Sherali et al. (2003), some departments could have fixed dimensions because of some specific physical characteristics of the activities of that department. Thus, the modified model considering both fixed and variable departments is necessary.

As mentioned, we set type A departments as those with flexible dimensions and type B departments as those with fixed width and length. Initially, this categorization was introduced in Chae (2014). The characteristics of these department types are shown in Fig. 1. Different approaches are needed to model those different types of department layout problems. For the layout problem for type A departments, the lengths and widths are decision variables as are the centroids of each department. In the case of layout problem with type B departments, the position of the centroid of each department is the main concern. However, the latter model is not easier since the model needs to determine the precise orientation of each department. Thus handling these two types of departments in a model increases the difficulty because of the addition of new binary variables.

There are two basic approaches to include these two different types of departments in a model. The first is that the constraints for type B departments are inserted to the layout model for type A departments. The second is the opposite: type A department constraints are inserted into the model for type B departments. The former method is more reasonable since starting from a model which can handle more flexible layouts and constraining some of these to be less flexible, is more straightforward than adding flexibility to a model with more constrained layouts. Therefore, that is the approach we use in our work. The base model for type A

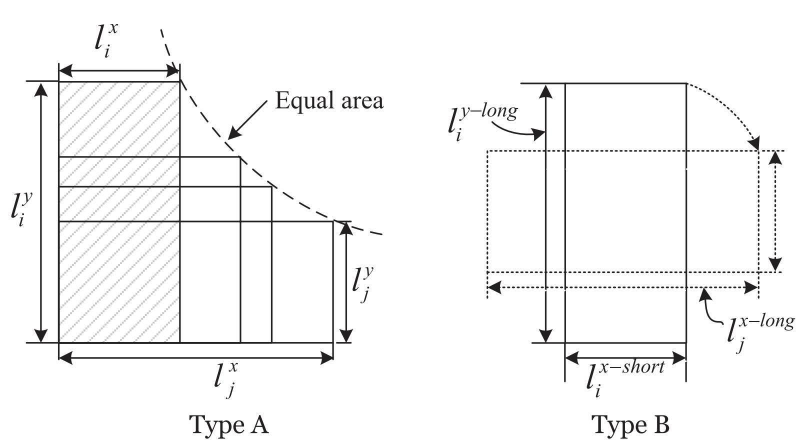

Fig. 1. Characteristics of type A and B departments.