European Journal of Operational Research 201 (2010) 171–182

Contents lists available at ScienceDirect

European Journal of Operational Research

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

Production, Manufacturing and Logistics

Heuristics for the dynamic facility layout problem with unequal-area departments

Alan R. McKendall Jr. *, Artak Hakobyan

Department of Industrial and Management Systems Engineering, West Virginia University, 325A Mineral Resources Building, Morgantown, WV 26506, USA

ARTICLE INFO

Article history:
Received 30 June 2008
Accepted 23 February 2009
Available online 1 March 2009

Keywords:
Facilities planning and design
Dynamic facility layout problem
Unequal-area departments
Tabu search
Boundary search
Meta-heuristic

ABSTRACT

The dynamic facility layout problem (DFLP) is the problem of finding positions of departments on the plant floor for multiple periods (material flows between departments change during the planning horizon) such that departments do not overlap, and the sum of the material handling and rearrangement costs is minimized. In this paper, the departments may have unequal-areas and free orientations, and the layout for each period is generated on the continuous plant floor. Because of the complexity of the problem, only small-size problems can be solved in reasonable time using exact techniques. As a result, a boundary search (construction) technique, which places departments along the boundaries of already placed departments, is developed for the DFLP. 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 demonstrate the effectiveness of the heuristics.

Published by Elsevier B.V.

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). Some of the factors, which may change material flows, are as follows and were taken from Shore and Tompkins (1980):

- Changes in the design of an existing product.
- The addition or deletion of products.
- Replacement of existing production equipment.
- Shorter product life cycles.
- Changes in the production quantities and associated production schedules.

For a review of the SFLP, see Kusiak and Heragu (1987) and Meller and Gau (1996).

The DFLP is the problem of finding positions of departments on the plant floor for multiple periods such that departments do not overlap, and the sum of the material handling and rearrangement costs is minimized. In other words, for each period in the planning horizon, the layout is determined such that the sum of the material handling cost for each layout and the cost of rearranging departments between each pair of consecutive layouts is minimized. Rosenblatt (1986) was the first to present solution techniques (i.e., optimal and heuristic procedures based on dynamic programming) for the DFLP. However, the author considered equal area departments and used the discrete representation of the layout (used equal-size grids to represent departments on the plant floor). Most of the solution techniques available in the literature for the DFLP use the discrete representation of the layout and are approximation techniques, since the DFLP is computationally intractable. For a review of the problem assumptions and solution techniques for the DFLP, see Balakrishnan and Cheng (1998) and Kulturel-Konak (2007).

In this paper, a boundary search technique, which places departments along the boundaries of already placed departments, is used to construct a solution for the DFLP under the following assumptions.

* Corresponding author. Tel.: +1 304 293 4607.
E-mail address: armckendall@mail.wvu.edu (A.R. McKendall Jr.).

0377-2217/$ - see front matter Published by Elsevier B.V.
doi:10.1016/j.ejor.2009.02.028

(1) Departments may have unequal-areas. In other words, departments are either square or rectangular in shape.
(2) Department areas are fixed for each period but may vary from one period to another.
(3) Departments may have free orientations (i.e., departments may be either horizontally or vertically oriented). If the longer side of the department is parallel to the *x*-axis, the department is horizontally oriented. In contrast, if the longer side is parallel to the *y*-axis, the department is vertically oriented.
(4) The layout for each period uses the continuous representation of the plant floor.
(5) The objective of the DFLP is to obtain a layout for each period in the planning horizon such that the sum of material handling and rearrangement costs is minimized. Rearrangement cost is incurred when a department is said to be rearranged (i.e., department centroid or dimensions change in consecutive periods).

Once a solution is constructed using the boundary search technique, a tabu search heuristic is used to improve the solution.

Montreuil and Venkatadri (1991) presented the first formulation for the DFLP with unequal-area variable shape departments. Their mathematical formulation does not require binary variables, since the relative positions of pairs of departments are known. This linear programming (LP) model was improved by Montreuil and Laforge (1992) by relaxing some assumptions. Other papers, which considered the DFLP with unequal-area variable shape departments, are Lacksonen (1994, 1997). In both cases, the author used a mixed integer linear programming (MILP) model to solve their DFLP. The only papers, in the literature, known to the authors, which consider the DFLP under assumptions (1)–(5), are Yang and Peters (1998) and Dunker et al. (2005). Yang and Peters (1998) considered time windows when solving the DFLP. The authors solve a series of SFLPs, one for each time window, using a MILP formulation. The structured hexagonal adjacency graph from Goetschalckx (1992) is used to fix the binary variables corresponding to relative positions of departments in each time window. Dunker et al. (2005) used a hybrid approach, which combined dynamic programming with a genetic algorithm. Each gene stores information about the relative positions of departments in a layout for a period. The solution corresponding to a gene is obtained by solving a relaxed MILP formulation for the SFLP in which the only unknown binary variables are variables representing the orientations of departments and configurations of input/output stations. Dynamic programming is used to evaluate the fitness of each gene.

All the solution techniques, which use the continuous representation of the layout for the DFLP with unequal-area departments, use either a LP or MILP formulation to determine the layout for each period (i.e., the layout plan). However, in this paper, the boundary search technique, which is less costly computationally, is used to determine the layout plan.

The structure of this paper is as follows. In Section 2, a mathematical formulation for the DFLP with unequal-area departments is presented. In Section 3, a boundary search heuristic and a tabu search heuristic are presented for the DFLP. Computational results for the heuristics are presented in Section 4, and Section 5 concludes the paper.

2. A mathematical formulation for the DFLP

In this section, a MILP formulation is presented for the DFLP with unequal-area departments. A similar formulation can be found in Dunker et al. (2005), except that in this paper input/output stations are at the centroids of the departments. First, the notation is given as follows. It is important to note that most of the indexes and parameters defined in this section are used later for the heuristics.

Indexes
$i, j = 1,\ldots,N$ where N is the number of departments
$t = 1,\ldots,T$ where T is the number of periods

Parameters
F_{tij} cost to transport materials a unit distance from department i to department j in period t
$F'_{tij} = F_{tij} + F_{tji}$ total cost to transport materials a unit distance between departments i and j in period t (upper triangular matrix)
R_{ti} rearrangement cost of shifting department i at the beginning of period t
Sh_{ti} shorter side length of department i in period t
Lng_{ti} longer side length of department i in period t

$$DeptOrient_{ti} = \begin{cases} 0 & \text{if department } i \text{ in period } t \text{ can have any orientation} \\ 1 & \text{if department } i \text{ in period } t \text{ is restricted to horizontal orientation} \\ 2 & \text{if department } i \text{ in period } t \text{ is restricted to vertical orientation} \end{cases}$$

L length of the plant floor
W width of the plant floor
M a large number

Variables
(x_{ti}, y_{ti}) the centroid (or location) of department i in period t
l_{ti}, w_{ti} the length and width of department i in period t
x_p_{tij}, y_p_{tij} horizontal and vertical distances between the centers of departments i and j in period t

$$h_{ti} = \begin{cases} 1, & \text{If department } i \text{ has horizontal orientation in period } t \\ 0, & \text{Otherwise} \end{cases}$$

$$left_{tij} = \begin{cases} 1 & \text{if department } i \text{ is to the left of department } j \text{ in period } t (\text{i.e., } x_{ti} + 0.5^* l_{ti} \leqslant x_{tj} - 0.5^* l_{tj}) \\ 0 & \text{Otherwise} \end{cases}$$

$$below_{tij} = \begin{cases} 1 & \text{if department } i \text{ is below department } j \text{ in period } t (\text{i.e., } y_{ti} + 0.5^* w_{ti} \leqslant y_{tj} - 0.5^* w_{tj}) \\ 0 & \text{otherwise} \end{cases}$$

$$r_{ti} = \begin{cases} 1 & \text{if department } i \text{ is rearranged at the beginning of period } t \\ 0 & \text{otherwise} \end{cases}$$