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Full Length Research Paper

A mixed integer programming formulation for multi-floor layout

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In this paper, the two-floor facility layout problem with unequal departmental areas in multi-bay environments is addressed. A mixed integer programming formulation is developed to find the optimal solution to the problem. This model determines position and number of elevators with consideration of conflicting objectives simultaneously. Objectives include to minimize material handling cost and to maximize closeness rating. A memetic algorithm (MA), is designed to solve the problem and it is compared with the corresponding genetic algorithm for large-sized test instances and with a commercial linear programming solver solution to small-sized test instances. Computational results proved the efficiency of solution procedure to the problem.

Key words: Mixed integer programming, multi floor layout, multi-objective.

INTRODUCTION

One of the oldest activities done by industrial engineers is facilities planning. The term facilities planning can be divided into two parts: facility location and facility layout. The latter is one of the foremost problems of modern manufacturing systems and has three sections: layout design, material handling system design and facility system design (Tompkins et al., 2003).

Determining the most efficient arrangement of physical departments within a facility is defined as a facility layout problem (FLP). Layout problems are known to be complex and are generally NP-Hard (Enea et al., 2005). Classical approaches to layout designing problems tend to maximize the efficiency of layouts measured by the handling cost related to the interdepartmental flow and the distance among the departments. However, the actual problem involves several conflicting objectives hence requires a multi-objective formulation (Aiello et al., 2006). The common objectives to layout designing are minimi-zing the total cost of material transportation and maximi-zing the total closeness rating between each two departments. In some cases they are combined as below (Meller and Gau, 1996):

$$\min \alpha \sum_{j}\sum_{i}(f_{ij}c_{ij})d_{ij} - (1-\alpha)\sum_{j}\sum_{i} r_{ij}x_{ij} \qquad (1)$$

is weighted coefficient of objective functions That is material flow between departments and ,is the cost of moving in unit distance of material flow between departments of and , is closeness ratio between departments of and is an indicator which is when departments of and have common boundary and otherwise is zero. Setting the parameter α has been studied by Meller and Gau, (1997).

Aiello et al. [2006] represented a two-stage multi-objective flexible-bay layout. Genetic Algorithm (GA) was used to find Pareto-optimal in the first stage and the selection of an optimal solution was carried out by Electre method in second stage. These objectives considered minimization of the material handling cost, maximization of the satisfaction of weighted adjacency, maximization of the satisfaction of distance requests and maximization of the satisfaction of aspect ratio requests. Pierreval et al. (2003) described evolutionary approaches to the design of manufacturing systems. Chen and Sha (2005) presented a multi-objective heuristic which contained work-

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flow, closeness rating, material-handling time and hazardous movement. ßahin and Türkbey (2008) proposed simulated annealing algorithm to find Pareto solutions for multi-objective facility layout problems including total material handling cost and closeness rating. A qualitative and quantitative multi-objective approach to facility layout was developed by Peters and Yang (1997). Peer and Sharma (2008) considered material handling and closeness relationships in multi-goal facilities layout. Konak et al. (20-06) conducted a survey on multi-objective optimization using genetic algorithms and Loiola et al. (2007) provided a review paper for the quadratic assignment problem (QAP) which concerned multi-objective QAP.

In this paper we consider both issue of multi objective and multi floor. Nowadays, when it comes to the construction of a factory in an urban area, land providing is generally insufficient and expensive. The limitation of available horizontal space creates a need to use a vertical dimension of the workshop. Then, it can be relevant to locate the facilities on several floors Drira et al. (2007).

Meller and Bozer (1997) compared approaches of multi-floor facility layout. Lee et al. (2005) used GA multi-floor layout which minimized the total cost of material transportation and adjacency requirement between departments while satisfied constraints of area and aspect ratios of departments. A five-segmented chromosome represented multi-floor facility layout. Many firms are likely to consider renovating or constructing multi-floor buildings, particularly in those cases where land is limited (Bozer and Meller, 1994). Matsuzaki et al. (1999) developed a heuristic for multi-floor facility layout considering capacity of elevator. Patsiatzis et al. (2002) presented a mixed integer linear formulation for the multi-floor facility layout problem. This work was extended model of the single-floor work of Papageorgiou and Rotstein (1998).

We focus on flexible bay-structured layout. In the bay-structured facility layout problems, a pre-specified rectangular floor space is first partitioned horizontally or vertically into bays and then each bay is divided into blocks with equal width but different lengths. Some typical works in bay layout are (Aiello et al., 2006; Arapoglu et al., 2001; Castillo and Peters, 2004; Chae and Peters, 2006; Chen et al., 2002; Eklund et al., 2006; Enea et al., 2005; Garey and Johnson, 1979; Konak et al., 2006; Kulturel-Konak et al., 2004; Meller, 1997; Peters and Yang, 1997; Tate and Smith, 1995).

In this paper we formulate a multi floor layout considering conflicting objectives. Objectives are common-used in previous works and include to minimize material handling cost and to maximize closeness rating.

MATHEMATICAL MODEL

Sets and Indices

$N = \{1, 2, \dots, n\}$: Set of cells in block layout graph .

A. Variables

$$z_{ik} = \begin{cases} 1, & \text{If department } i \text{ is aasigned to bay } k \text{ in the first floor} \\ 0, & \text{Otherwise} \end{cases}$$

$$z'_{ik} = \begin{cases} 1, & \text{If department } i \text{ is aasigned to bay } k \text{ in the second floor} \\ 0, & \text{Otherwise} \end{cases}$$

$$r_{ij} = \begin{cases} 1, & \text{If department } i \text{ is located above department } j \text{ in the same bay} \\ 0, & \text{Otherwise} \end{cases}$$

$$\delta_k = \begin{cases} 1, & \text{If bay } k \text{ is occupied in first floor} \\ 0, & \text{Otherwise} \end{cases}$$

$$\delta'_k = \begin{cases} 1, & \text{If bay } k \text{ is occupied in second floor} \\ 0, & \text{Otherwise} \end{cases}$$

$$G_i = \begin{cases} 1, & \text{If department } i \text{ is located in first floor} \\ 0, & \text{Otherwise} \end{cases}$$

$$y_{ij} = \begin{cases} 1, & \text{If department } i \text{ and } j \text{ have common boundary} \\ 0, & \text{Otherwise} \end{cases}$$

w_k Width (the length in the x-axis direction) of bay i in first floor

w'_k Width (the length in the x-axis direction) of bay i in second floor

w^1_{ik} Width (the length in the x-axis direction) of bay i in bay k in first floor

w^2_{ik} Width (the length in the x-axis direction) of bay i in bay k in second floor

l^y_i Height (the length in the y-axis direction) of department i in first floor

$l^{\bar{y}}_i$ Height (the length in the y-axis direction) of department i in second floor

(a^x_i, a^y_i) Coordinates of the centroid of department i in first floor

$(a^{\bar{x}}_i, a^{\bar{y}}_i)$ Coordinates of the centroid of department i in second floor

d^{x}_{ij} Distance between the centroid of departments i and j, in the x-axis direction in first floor

$d^{\bar{x}}_{ij}$ Distance between the centroid of departments i and j, in the x-axis direction in second floor

d^{y}_{ij} Distance between the centroid of departments i and j in the y-axis direction in first floor

$d^{\bar{y}}_{ij}$ Distance between the centroid of departments i and j in the y-axis direction in second floor

h_{ik}	Height (the length in the y-axis direction) of department i in first floor
h'_{ik}	Height (the length in the y-axis direction) of department i in second floor
$(\overline{Up}_i^x, \overline{Up}_i^y)$	Coordinates of the northeastern corner of department i
(Lo_i^x, Lo_i^y)	Coordinates of the southwestern corner of department i

$$s_1 = \begin{cases} 1, & \text{If the first floor is used} \\ 0, & \text{Otherwise} \end{cases}$$

$$s_2 = \begin{cases} 1, & \text{If fist elevator is located in southwest corner of facility} \\ 0, & \text{If fist elevator is located in northwest corner of facility} \end{cases}$$

$$s_3 = \begin{cases} 1, & \text{If second elevator is located in southeast corner of facility} \\ 0, & \text{If second elevator is located in northeast corner of facility} \end{cases}$$

B. Parameters

n:	Number of departments
W:	Width of the facility along the *x*-axis
H:	Width of the facility along the *y*-axis
a_i:	Area requirement of department i
α_i:	Aspect ratio of department i
l_i^{max}:	Maximum permissible side length of department i
l_i^{min}:	Maximum permissible side length of department i
f_{ij}:	Amount of material flow between departments i and j
c_{ij}:	Amount of material cost between departments i and i if they would be in different floors in *y*-axis
adj_{ij}:	Adjacency ratio between departments i and j
He	Distance between two department in *z*-axis
p_1, p_2:	Weights of objective functions

C. Assumptions

i. The coordinates of the southwestern corner of the facility are (0, 0).

ii. In the model description, the long side of the facility is along the x-axis direction, and bays are assumed to be vertically arranged within the facility.

iii. If a department is assigned to a bay, then the bay must be completely filled.

iv. If the aspect ratio is specified to control departmental shapes, then

$$l_i^{min} = \sqrt{a_i/\alpha_i}, \; l_i^{max} = \sqrt{a_i \alpha_i}$$

D. Problem formulation

In our paper, we extend their model with following constraints:

$$W(2 - G_i - G_j) + d_{ij}^x \geq (o_i^x - o_j^x) \quad \forall i < j, \quad (1)$$

$$W(2 - G_i - G_j) + d_{ij}^x \geq (o_j^x - o_i^x) \quad \forall i < j, \quad (2)$$

$$L(2 - G_i - G_j) + d_{ij}^y \geq (o_j^y - o_i^y) \quad \forall i < j, \quad (3)$$

$$L(2 - G_i - G_j) + d_{ij}^y \geq (o_j^y - o_i^y) \quad \forall i < j, \quad (4)$$

$$W\left(2 - (1 - G_i) - (1 - G_j)\right) + d_{ij}^{\prime x} \geq (o_i^{\prime x} - o_j^{\prime x}) \quad \forall i < j, \quad (5)$$

$$W\left(2 - (1 - G_i) - (1 - G_j)\right) + d_{ij}^{\prime x} \geq (o_j^{\prime x} - o_i^{\prime x}) \quad \forall i < j, \quad (6)$$

$$L\left(2 - (1 - G_i) - (1 - G_j)\right) + d_{ij}^{\prime y} \geq (o_i^{y} - o_j^{y}) \quad \forall i < j, \quad (7)$$

$$L\left(2 - (1 - G_i) - (1 - G_j)\right) + d_{ij}^{\prime y} \geq (o_j^{y} - o_i^{y}) \quad \forall i < j, \quad (8)$$

Constraints (1)–(8) linearize the absolute value term in the rectilinear distance function in first and second floor.

$$\sum_k z_{ik} = G_i \quad \forall i, \quad (9)$$

$$\sum_k z'_{ik} = 1 - G_i \quad \forall i, \quad (10)$$

Constraints (9), (10) state that each department is located in a bay.

$$w_k = \frac{1}{L}\sum_i z_{ik} a_i \quad \forall k, \quad (11)$$

$$w'_k = \frac{1}{L}\sum_i z'_{ik} a_i \quad \forall k, \quad (12)$$

$$l_i^{min} z_{ik} \leq w_k \leq l_i^{max} + W(1 - z_{ik}) \quad \forall i, k, \quad (13)$$

$$l_i^{min} z'_{ik} \leq w'_k \leq l_i^{max} + W(1 - z'_{ik}) \quad \forall i, k, \quad (14)$$

$$o_i^x \leq \sum_{j \leq k} w_j - 0.5 w_k + (W - l_i^{min})(1 - z_{ik}) \quad \forall i, j, k, \quad (15)$$

$$o_i^x \geq \sum_{j \leq k} w_j - 0.5 w_k - (W - l_i^{min})(1 - z_{ik}) \quad \forall i, j, k, \quad (16)$$

$$o_i^{\prime x} \leq \sum_{j \leq k} w'_j - 0.5 w'_k + (W - l_i^{min})(1 - z'_{ik}) \quad \forall i, j, k, \quad (17)$$

$$o_i^{\prime x} \geq \sum_{j \leq k} w'_j - 0.5 w'_k - (W - l_i^{min})(1 - z'_{ik}) \quad \forall i, j, k, \quad (18)$$

$$\frac{h_{ik}}{a_i} - \frac{h_{jk}}{a_j} - \max\left\{\frac{l_i^{max}}{a_i}, \frac{l_j^{max}}{a_j}\right\}(2 - z_{ik} - z_{jk}) \leq \quad \forall i, j, k, \quad (19)$$

$$\frac{h_{ik}}{a_i} - \frac{h_{jk}}{a_j} + \max\left\{\frac{l_i^{max}}{a_i}, \frac{l_j^{max}}{a_j}\right\}(2 - z_{ik} - z_{jk}) \geq \quad \forall i, j, k, \quad (20)$$

$$\frac{h'_{ik}}{a_i} - \frac{h'_{jk}}{a_j} - \max\left\{\frac{l_i^{max}}{a_i}, \frac{l_j^{max}}{a_j}\right\}(2 - z'_{ik} - z'_{jk}) \leq \quad \forall i, j, k, \quad (21)$$

$$\frac{h'_{ik}}{a_i} - \frac{h'_{jk}}{a_j} + max\left\{\frac{l_i^{max}}{a_i}, \frac{l_j^{max}}{a_j}\right\}\left(2 - z'_{ik} \quad \forall i,j,k, \qquad (22)$$

$$\sum_i h_{ik} = H\delta_k \quad \forall i,k, \qquad (23)$$

$$\sum_i h'_{ik} = H\delta'_k \quad \forall i,k, \qquad (24)$$

$$l_i^{min} z_{ik} \le h_{ik} \le l_i^{max} z_{ik} \quad \forall i,k, \qquad (25)$$

$$l_i^{min} z'_{ik} \le h'_{ik} \le l_i^{max} z'_{ik} \quad \forall i,k, \qquad (26)$$

$$\sum_k h_{ik} = t_i^{\bar{y}} \quad \forall i,k, \qquad (27)$$

$$\sum_k h'_{ik} = l_i^{\bar{y}} \quad \forall i,k, \qquad (28)$$

$$o_i^{\bar{y}} - 0.5t_i^{y} \ge o_j^{\bar{y}} + 0.5t_i^{\bar{y}} - H(1 - \tau_{ij}) \quad \forall i \ne j, \qquad (29)$$

$$o_i^{\bar{y}} - 0.5l_i^{\bar{y}} \ge o_j^{\bar{y}} + 0.5l_i^{\bar{y}} - H(1 - \tau_{ij}) \quad \forall i \ne j, \qquad (30)$$

$$\tau_{ij} + \tau_{ji} \ge z_{ik}^{l} + z_{jk}^{l} - 1 \quad i < j, k, \qquad (31)$$

$$0.5t_i^{y} \le o_j^{\bar{y}} \le H - 0.5t_i^{\bar{y}} \quad \forall i, \qquad (32)$$

$$0.5l_i^{\bar{y}} \le o_j^{\bar{y}} \le H - 0.5l_i^{\bar{y}} \quad \forall i, \qquad (33)$$

Constraints (11)-(33) state restrictions of length and width of each department and determine coordination of each department.

$$w_i^1 = \sum_k z_{ik} w_k \quad \forall i,k, \qquad (34)$$

$$w_i^2 = \sum_k z'_{ik} w'_k \quad \forall i,k, \qquad (35)$$

$$o_i^x - o_j^x \le 0.5(w_i^1 + w_j^1) + W(1 - y_{ij}) \quad \forall i < j, \qquad (36)$$

$$o_j^x - o_i^x \le 0.5(w_i^1 + w_j^1) + W(1 - y_{ij}) \quad \forall i < j, \qquad (37)$$

$$o_i^{\bar{x}} - o_j^{\bar{x}} \le 0.5(w_i^2 + w_j^2) + W(1 - y_{ij}) \quad \forall i < j, \qquad (38)$$

$$o_j^{\bar{x}} - o_i^{\bar{x}} \le 0.5(w_i^2 + w_j^2) + W(1 - y_{ij}) \quad \forall i < j, \qquad (39)$$

$$o_i^y - o_j^y \le 0.5(t_i^y + t_j^y) + W(1 - y_{ij}) \quad \forall i < j, \qquad (40)$$

$$o_j^y - o_i^y \le 0.5(t_i^y + t_j^y) + W(1 - y_{ij}) \quad \forall i < j, \qquad (41)$$

$$o_i^{\bar{y}} - o_j^{\bar{y}} \le 0.5(l_i^{\bar{y}} + l_j^{\bar{y}}) + W(1 - y_{ij}) \quad \forall i < j, \qquad (42)$$

$$o_j^{\bar{y}} - o_i^{\bar{y}} \le 0.5(l_i^{\bar{y}} + l_j^{\bar{y}}) + W(1 - y_{ij}) \quad \forall i < j, \qquad (43)$$

$$y_{ij} \le G_i - G_j + 1 \quad \forall i < j, \qquad (44)$$

$$y_{ij} \le G_j - G_i + 1 \quad \forall i < j, \qquad (44)$$

Constraints (34) and (44) determine which two departments

$$F_1 = \sum_{j>i}\sum_i c_{ij} f_{ij} \begin{pmatrix} (d_{ij}^x + d_{ij}^y) \\ +(d_{ij}^{\bar{x}} + d_{ij}^{\bar{y}}) \end{pmatrix} \left(G_i G_j + (1 - G_i)(1 - G_j)\right) \qquad (45)$$

Statement (45) calculates material handling cost if two departments be in same floor.

$$I = (1 - s_1)s_2\left((o_i^x + o_i^y) + (o_j^{\bar{x}} + o_i^{\bar{y}})\right) \qquad (46)$$

$$II = (1 - s_1)(1 - s_2)\left(((L - o_i^y) + o_i^x) + ((L - o_i^{\bar{y}}) + o_i^{\bar{x}})\right) \qquad (47)$$

$$III = s_1 s_2\left(((W - o_i^{\bar{x}}) + o_i^y) + ((W - o_i^{\bar{x}}) + o_i^{\bar{y}})\right) \qquad (48)$$

$$IV = s_1(1 - s_2)\left(((W - o_i^{\bar{x}}) + (L - o_i^{\bar{y}})) + ((W - o_i^{\bar{x}}) + (L - o_i^{\bar{y}}))\right) \qquad (49)$$

$$F_2 = \sum_{j>i}\sum_i f_{ij}\left(c_{ij}He + (I + II + III + IV)\right)\left(G_i(1 - G_j) + G_j(1 - G_i)\right) \qquad (50)$$

(46)- (50) determine material handling cost between two departments if they are in different floors.

$$Up_i^{\bar{x}} = (o_i^x + o_i^{\bar{x}}) + 0.5(w_i^1 + w_i^2) \quad \forall i, \qquad (51)$$

$$Lo_i^{\bar{x}} = (o_i^x + o_i^{\bar{x}}) - 0.5(w_i^1 + w_i^2) \quad \forall i, \qquad (52)$$

$$Up_i^{\bar{y}} = (o_i^y + o_i^{\bar{y}}) + 0.5(t_i^y + l_i^{\bar{y}}) \quad \forall i, \qquad (53)$$

$$Lo_i^{\bar{y}} = (o_i^y + o_i^{\bar{y}}) - 0.5(t_i^y + l_i^{\bar{y}}) \quad \forall i, \qquad (54)$$

$$F_4 = \sum_{j>i}\sum_i adj_{ij} \begin{pmatrix} \left(min(Up_i^{\bar{x}}, Up_j^{\bar{x}}) - max(Lo_i^{\bar{x}}, Lo_j^{\bar{x}})\right) \\ + \\ \left(min(Up_i^{\bar{y}}, Up_j^{\bar{y}}) - max(Lo_i^{\bar{y}}, Lo_j^{\bar{y}})\right) \end{pmatrix} \left(G_i G_j + (1 - G_i)(1 - G_j)\right) \qquad (55)$$

(51)- (55) calculate summation of closeness rating between departments.

$$\min z = p_1(F_1 + F_2 + F_3) - p_2 F_4 \qquad (56)$$

$$p_1 + p_2 = 1;\ p_1, p_2 \ge 0 \qquad (57)$$

Objectives were formulated in a weighted form using (56) and (57)

$$A = xy; x \ge 0, y \in \{0,1\} \qquad (58)$$

$$A \le My; M \text{ is big number} \qquad (59)$$

$$A \le x + M(1 - y) \qquad (60)$$

$$A \ge x - M(1 - y) \qquad (61)$$

Constraints (58)-(61) can afford to linearize product of variable by integer variable.

Conclusion

In this paper, a multi-objective mixed integer linear programming model was developed to find the optimal solution to the multi-floor facility layout problem with unequal departmental areas in multi-bay environments where the bays are connected at one or two ends by an inter-bay material handling system.

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