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An Efficient Model for Layout Problems

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ABSTRACT

This paper offers an approach that could be useful for mathematical programming of diverse types of layout problems or even area allocation problems. By this approach, there is no need to large number of discrete variables. So large-scale layout problems could be modeled only by few continues variables. So they could be solved in polynomial time. This result has come from dividing area into discrete and continuous dimensions. In addition, defining decision variables as starting and finishing point of departments in the area makes it possible to model layout problem so. This paper also provides new technique that models basic constraints of layout problems. ***Note to Practitioners:*** *This paper provides a novel approach for designing facility layout and helps to select the most suitable layout for different production types and demands sizes. Therefore, a modeling approach proposed which designed the layout in a flexible way that discovers the near optimum solution for layout problem and omits other presumptions about layout planning.*

1. Introduction

Locating facilities and finding out what is the efficient design is an important and strategic issue for every manager. This problem is called Facility layout problem (FLP). In other words, FLP tries to determine the most effective arrangement and configuration of physical facilities. A good layout could save about 50% of the total operating cost [1]. The facilities layout problem has been used in different application areas such as design of various types of industrial, public facilities, commercial buildings, etc. [2].

In literature of facility layout problem (FLP) there are several types of layouts depended on the volume and variety of production. Fig. 1 shows these types and shows their application.

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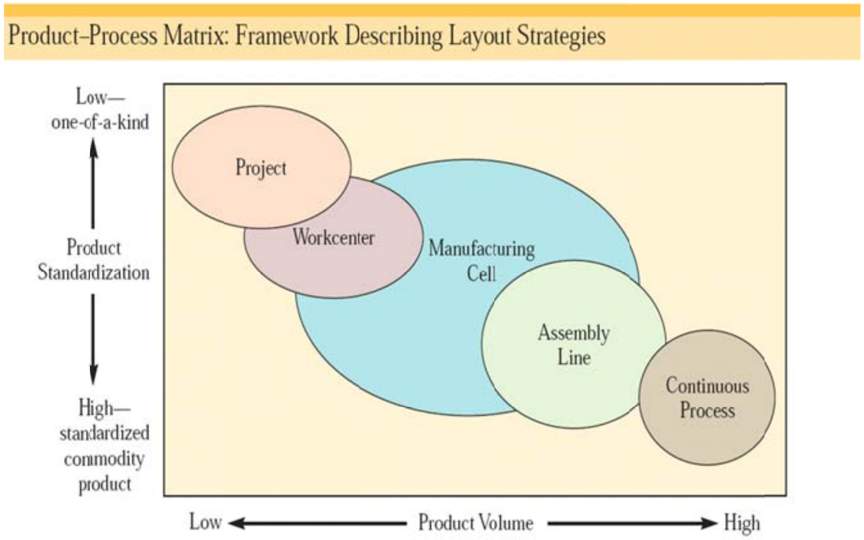

Fig. 1- Framework describing layout strategies

To have a better insight about Fig. 1 following more description is provided:

In a project layout, the product remains in a fixed location. Manufacturing equipment is moved to the product rather than vice versa. Examples of this format may be construction sites (houses and roads) and movie shooting lot. A workcenter is where similar equipment or operations are grouped. This type of layout is called a job shop too. A manufacturing cell is a dedicated area where products that are similar in processing requirements are produced. These cells are designed to perform a specific set of processes, and the cells are dedicated to a limited range of products. An assembly line is where work processes are arranged according to the progressive steps by which the product is made. A continuous process is similar to an assembly line in that production follows a predetermined sequence of stops, but the flow is continuous rather than discrete.

Designing a plant layout in form of mentioned structures imposes a constraint to the designing in which the proposed layout may not be the optimum one. Since deciding about type of layout is a qualitative process based on experience and expert judgment, is not necessarily accurate. It would be better to let the model itself find the most appropriate type of layout. On the other hand, there is no need to always design the layout in one of the existing types. The main goal of every layout planning and design is to minimize cost. There are several parameters affecting the cost in a plant such as

- **Types of Industries:** Synthetic process based industry, Analytic process based, Conditioning process based industry, Extractive process based industry, etc.
- **Types of Production System:** Continuous Production, Job Shop Production, Batch Production, etc.
- **Type of Production:** Whether the product is heavy or light, large or small, liquid or solid, etc.
- **Volume of Production:** Whether the production is in small quantity or in lots or batches, or in huge quantity.

If the above parameters do not impose a physical or critical constraint to plant layout, it will be better to use models, which are more flexible and could consider all aspects of layout planning such as flow among departments, size of every department area etc.

In addition, always there is no necessity to centralize several machines in a specific place as department. It is possible that placing machines in a form other department makes the production more effective and greater reduction in costs. In this paper, a new mathematical modeling approach is proposed to model and solve facility layout problem. The proposed model considers all valuable and important aspects of layout planning while not imposing any unnecessary constraints.

Usually generating the most proper and efficient layout is a complicated task. Based on [3] the physical layout design is NP-Hard. In real environments there are maybe large variations in areas which could subject to different types of constraints [4].

Different types of objectives have been used for modeling facility layout problems either to maximize adjacency requirement or to minimize the cost of transporting materials among departments [5],[6].

FLP is classified into two categories of equal and unequal area layout problems. The equal area layout problem tries to allocate a set of discrete facilities to a set of discrete locations while each facility is assigned to a single location. This type of facility layout problems are called “quadratic assignment problem” (QAP). The unequal area facility layout problem is more complex; therefore, it is much more difficult than QAP. In this case, each facility is represented by a polygon that should have enough flexibility in shape and location while maintaining a required area of the facility. This is called quadratic set covering problem (QSP) [5]. Both QAP and QSP have been proved to be NP-Complete problems and their computational time increases exponentially [7]. Classical QAP has been formulated by [8] as below:

$$\text{Min TMHC} = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n}\sum_{l=1}^{n} f_{ik} c_{ik} d_{jl} x_{ij} x_{kl} \quad (1)$$

Subject to

$$\sum_{j=1}^{n} x_{ij} = 1 \quad i = 1, 2, ..., n \quad (2)$$

$$\sum_{i=1}^{n} x_{ij} = 1 \quad j = 1, 2, ..., n \quad (3)$$

$$x_{ij} = 0 \text{ or } 1 \quad i, j = 1, 2, ..., n \quad (4)$$

Where TMHC is the total material handling cost among facilities; c_{ij} is the transportation cost for a unit material, for a unit distance between department i and j; f_{ik} is the material flow from facility i to facility k; d_{jl} is the rectilinear distance between the location j and l; and $x_{ij} = 1$ if facility i is assigned to location j and $x_{ij} = 0$, otherwise. The objective function is to minimize the total material handling cost among facilities. Constraints (2) and (4) ensure that exactly one department is assigned to each location. Constraints (3) and (4) state that each location is allowed to be chosen by only one department.

Historically, objective functions in facility layout problems are modeled as either the quantitative total material handling cost (TMHC) or the qualitative total adjacency score (TAS) of closeness among departments.

Armour and Buffa [9] proposed a heuristic algorithm to solve the quadratic assignment problem (QAP) model which determines the exact assignment of different departments on an existing location grid and its objective function is about TMHC. Rosenblatt [10] used a method to combine both quantitative and qualitative measures into a single objective function. Dutta and Sahu [11] developed a model which is similar to the model of Rosenblatt, but there is a difference in their solution methodology used to solve the problem. A more complicated model is presented by Fortenberry and Cox [12] which assigns weights to the distance between a pair of departments in the facility with the closeness rating score for the two departments. Meller and Gau [13] modify the objective function of the facility layout problem to follow the basic material handling cost structure.

In another classification, the Facility Layout Problem has been modeled as a quadratic assignment problem, a quadratic set covering problem, a linear integer programming problem, a mixed integer programming problem, and a graph theoretical problem [7, 14, 15].

Graph theory is useful for the facility layout problems because graphs easily enable us to capture the adjacency information and model the facility layout problem [16]. A review of graph theory applications in the facilities layout problem could be found in Foulds [17] and Hassan and Hogg [18].

Over the years some computer based heuristic layout algorithms have been developed. Departments are assigned to floor space one at a time with a construction type layout algorithm, for example ALDEP [19], CORELAP [20], and PLANET [21] or an initial layout design is improved by an improvement layout design algorithm, for example CRAFT [9], COFAD [22], MULTIPLE [23] and SABLE [13]. Layouts provided by these computerized algorithms are approximate layout design solutions, and they may suggest an undesired department shape or an infeasible solution [24].

In recent years, different types of heuristics have been developed to solve facilities layout problems. [11], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [26] developed a genetic algorithm, [36] combined GA and Electre method to solve facility layout problems. [37] used tabu search, [38], [39], [40] used simulated annealing, and [41], [42] used ant colony optimization to solve the problem.

In section 2 proposed approach discussed. Objective function of the model is described in section 2.1. Then in section 2.2 basic constraints of layout problem are described. Overall model have been shown in section 3. Section 4 describes conclusions of the paper and the future researches have come in section 5. Finally, in section 6 the references are listed.

2.New Approach

In this approach, area is supposed as a mixture of discrete and continuous dimensions. The main contribution of this paper is modeling layout problem by a linear model that is due to our approach in dividing area in mentioned way. By this type of model, global optimum for large-scale layout problems could be found in polynomial time.There are other contributions in this model that comes from new representations of layout problem logical and operational constraints and objectives. These will come further.

First, area must be divided into the rows and columns. The rows are supposed the criterion of dividing area. It means that the rows are discrete and the columns are continuous. That means area divided into rows. The rows numbers are related to the accuracy and tolerance that is needed.

The method of finding departments is to determine starting and finishing points of each department in each row. By setting constraints, resulting shapes will change to the required form.

Variables of the model are as follow:

Definition 1. S_{ir} is a continuous variable that represents starting point of ith department in rth row.

Definition 2. F_{ir} is a continuous variable that represents finishing point of ith department in rth row.

R_{ij} is a continuous parameter that represents relation of ith and jth departments. And a_i is a continuous parameter that represents the area of ith department.

For example in the following Fig. 2, $S_{11} = 0$ says that department 1 in row 1 starts at 0 and $F_{11} = 2.5$ says that department 1 in row 1 finishes at 2.5.

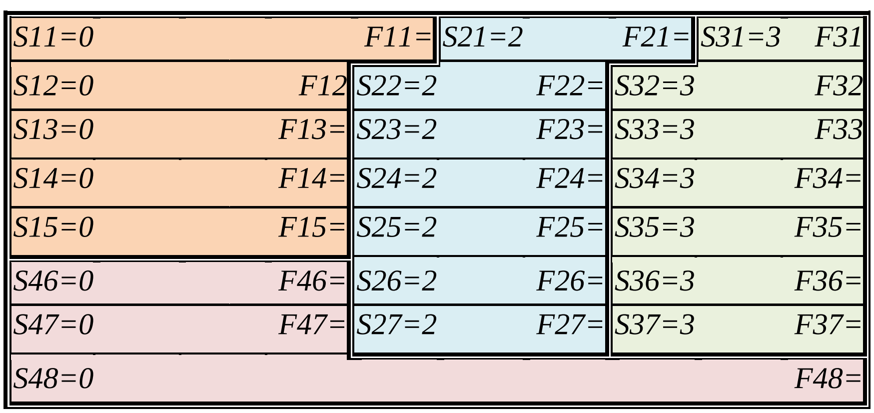

Fig. 2. An example of proposed approach in determining departments' layout

In this method, equality of S_{ir} and F_{ir} means the department in the related row doesn't exist. This model could be used for all shapes of area if decision variables in each row could only get specified values that come from shape of area. For example, suppose white parts as allowed area in Fig. 3. Then by setting some constraints such as following constraint, allowed area will shape:

$$S_{i4} \geq 0.4 \quad \forall i$$

This means all departments starting points in row 4 should be after 0.4. Such constraints like [38] for rows 5, 6, 7 and 8 will result in desired area.

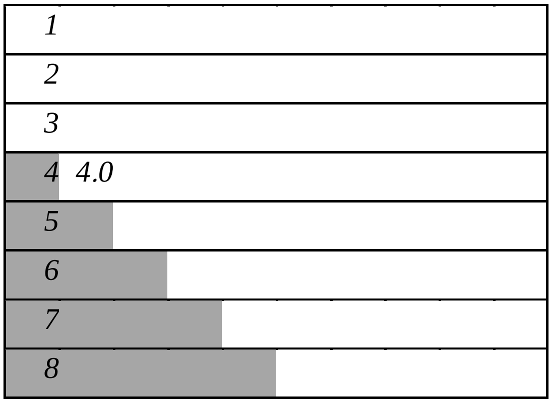

Fig. 3. White part is desired shape

Also there is a simpler way to gain such shape by assigning unallowable parts to one or some virtual departments before solving the problem. As a contribution, the row and column in this model could switch so numbers of discrete variables and thus the size of the problem will reduce.

2.1- Objective Function

Although in this model various objectives could be defined such as TMHC or TAS, but in this paper objective is defined by distance and nearness of more relative departments .Also, it is important to form the shapes as rectangular as possible. Notice that with these objective functions model becomes quadratic.

$$Min\ C_1 \sum_i \sum_j \sum_r [\, (S_{i(r+1)} - S_{ir})^2 + (F_{i(r+1)} - F_{ir}\ S_{ir})] \qquad (6)$$

First parentheses express the amount of change in starting and finishing points of each department in each row with respect to the next row. As shown in Fig. 4 and Fig. 5 by minimizing this expression, model seeks to avoid peaks, troughs and severe slopes and makes shapes as rectangular as possible.

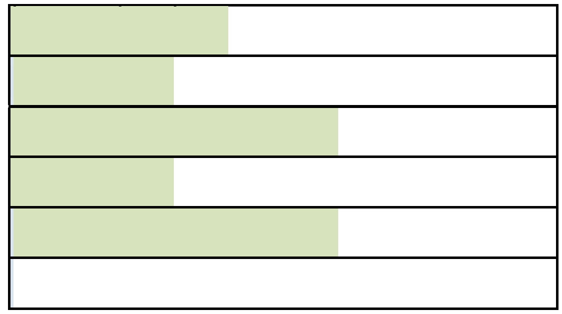

Fig. 4. Undesired shape

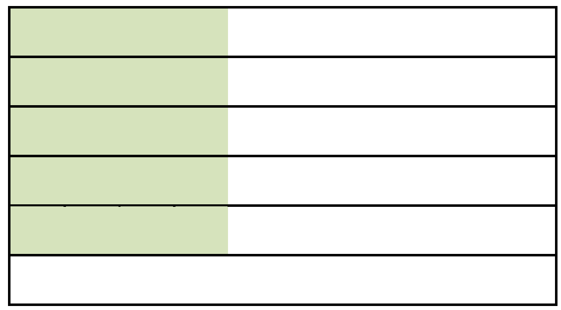

Fig. 5. Desired (rectangular) shape

The second phrase in the objective function (6), $R_{ij}(F_{ir} - S_{jr})(F_{jr} - S_{ir})$ represents the start to finish distance of each department with other departments multiplied by relationship amount between them. Increasing this phrase makes two parts, which have more relation, nearer. Therefore, by minimizing the negative of this phrase more related department will be nearer. Notice that proportion of C_1 to C_2 expresses preference of second objective to first objective.

2.2- Constraints

The first constraint must be considered is the one which prohibits overlapping of departments. Then filled area in each row must be equal to subtraction of overall starting and finishing points of all departments in the row. Fig. 6 and Fig. 7 show this.

Fig. 6. Area of each one is 2 but total area is 3.5 (confluence)

Fig. 7. Area of each one is 2 but total area is 4 (confluence resolved)

Mentioned constraint in mathematical expression:

$$\sum_{i}\sum_{j}\sum_{r}\left[[(F_{ir}-S_{jr})(F_{jr}-S_{ir})][(F_{ir}-S_{ir})(F_{jr}-S_{jr})]\right] \le 0 \qquad \forall i,j > i,r \qquad (7)$$

Also, each department must have wanted area*:*

$$\sum_{r}(F_{ir}-S_{ir}) = a_i \qquad \forall i,r \qquad (8)$$

For continuity of departments in sequential rows, the starting point of each department must be before the finishing point in the next row and the finishing point of each department must be after the starting point in the next row.

Continuity of departments in sequential rows guaranteed by following constraints:

$$S_{ir} \le F_{i(r+1)} \qquad \forall i,r \qquad (9)$$

$$F_{ir} \ge S_{i(r+1)} \qquad \forall i,r \qquad (10)$$

Inequality (9) causes that following situation not to occur as shown in Fig. 8 and Fig. 9.

Fig. 8. Discontinuity

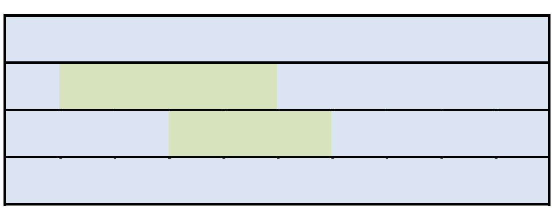

Fig. 9. Discontinuity

Inequality (10) causes that following situation not to occur as shown in Fig. 8 and Fig. 9.

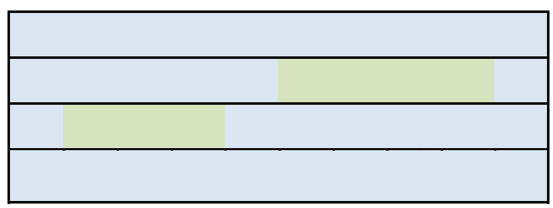

Fig. 10. Discontinuity

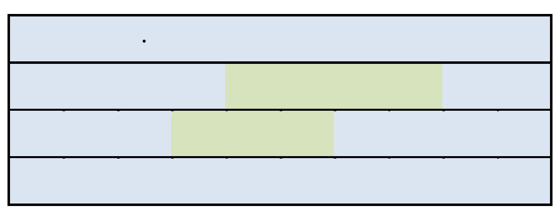

Fig. 11. Continuity

3. Overall Model

$$Min\ C_1 \sum_i \sum_j \sum_r [(S_{i(r+1)} - S_{ir})^2 + (F_{i(r+1)} - F_{ir})^2] + C_2 \sum_i \sum_j \sum_r [R_{ij}[(S_{ir} + F_{ir})/2 - (S_{jr} + F_{jr})/2]]^2 \quad (6)$$

$$\sum_i \sum_j \sum_r \left[[(F_{ir} - S_{jr})(F_{jr} - S_{ir})][(F_{ir} - S_{ir})(F_{jr} - S_{jr})]\right] \le 0 \quad \forall i, j > i, r \quad (7)$$

$$\sum_r (F_{ir} - S_{ir}) = a_i \quad \forall i, r \quad (8)$$

$$S_{ir} \le F_{i(r+1)} \quad \forall i, r \quad (9)$$

$$F_{ir} \ge S_{i(r+1)} \quad \forall i, r \quad (10)$$

4.Conclusions

This approach provides an efficient model for layout problems that could practically solve large-scale problems. The main contribution of this approach is how to divide area into discrete and continuous dimensions. Another contribution lies in how to represent basic constraints of layout problems such as avoiding overlapping, continuity, etc. So this model contains continuous variables and solves large-scale layout problems in polynomial time and gives us global optimum.

5.Future Researches

As mentioned above, this approach could be used for many space allocation problems such as distraction problem. Also by few changes, this approach could be used for time allocation problem such as scheduling.

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