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An Extended Mathematical Model for Multi-Floor Facility Layout Problems

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Abstract: *Multi-floor layout problems need to be modeled thoroughly considering all significant factors that have effect on the cost of multi-floor layout planning. In this research, the study objective was to develop a preliminary mathematical model of multi-floor layout problems with the goal to minimize the total fixed cost & inter-floor interaction cost. The study solved the numerical case study by extending genetic search codes of preliminary mathematical model. The objective of the study was achieved by adding two new notations of and representing the number of items going from facility i to facility p and number of barriers with which is faced between location j and q, respectively. Added notations are in both vertical and horizontal directions. Finally Computational results are presented that indicate this model solves the multi-floor layout problems more cost-effective than the previous ones.*

Keywords: *Multi-floor layout problem, Genetic algorithm (GA), fixed cost, Inter-floor cost.*

INTRODUCTION

Layout is an important issue not only for manufacturing companies but also for non-manufacturing organizations (Sahu, Raizada and Agiwal, “A Genetic Algorithm to Multi-Floor Facility Layout Problem”). Reference (Lee, Roh and Jeong, 2005) believes that the main objective of layout is to ensure that there is a leveled flow of work, material and information in the system. Based on reference (Bozer, Meller and Erlebacher, 1994), the facility layout and its design effect remarkably on how the work is performed, the flow of work, materials and information ongoing in the system. The key point to have good facility layout and design is the integration of people and their needs (personnel and customers), materials (raw, finishes, and in process) and machinery in a good manner that gives out a smooth well-functioning system (Kochhar, Foster and Heragu, 1998). According to reference (Johnson, 1982), to generate new alternatives to the existing layouts is a critical step in the process of facilities planning. Given particular interactions that occur between facilities, the facility layout problem is going to determine the "most efficient" positioning of the facilities subjected to the constraints affected by the building, the site plan, the facility area, the decision maker and the service requirements. Hence, to grasp this efficient positioning (arrangement) there is a need to model the problem and solve it using heuristic methods that in the current case it will be Genetic Algorithm (GA).

Initially, reference (Kaku, Thompson and Baybars, 1988) developed a methodology for GA that composed of a few steps which are followed to move from one generation to the next. In each of generation the operators like mutation and crossover are utilized for reproducing new chromosomes. Then each of chromosome's performance is measured by some fitness function serves as a foundation for its selection to the next generation. It goes through this way so that the stopping condition is confirmed by fitness function (Jannat, Khaled and Paul, 2010).

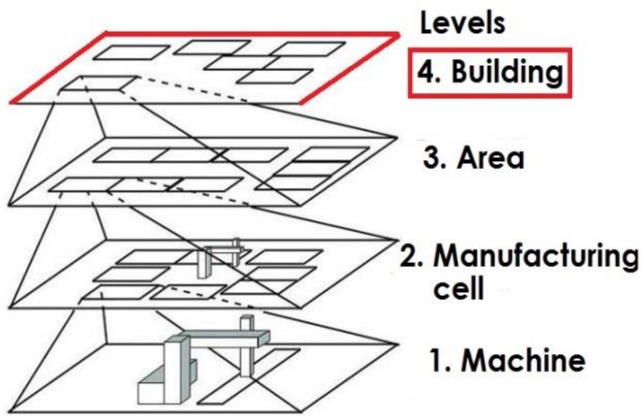

Figure 1: Different levels of manufacturing systems and the study level highlighted (Lee, Roh and Jeong, 2005)

Data gathering & analysis

Facility layout problem is to identify the related locations of different facilities like lathe department, grinding department, etc. It should be done in a manner that minimizes the total cost of installing and transporting material between them.

Preliminary mathematical model

According to reference (Wang, Hu and Ku, 2005) the problem is presented as:

$A = | a_{ij} |$, is the fixed cost matrix where a_{ij} is the fixed cost of installing facility i at location j.

$F = | f_{ij} |$, is the flow cost matrix where f_{ij} is the cost per unit distance of transporting the material from facility i to facility j.

$D = | d_{ij} |$, is the distance matrix where d_{ij} is the distance from location i to location j.

With these definitions, based on (Wang, Hu and Ku, 2005) the Facility Layout Problem is:

Minimize:

$$\sum_i \sum_j a_{ij}.x_{ij} + \sum_i \sum_j \sum_p \sum_q (f_{ip}.d_{jq}.x_{ij}.x_{pq}) \quad (1)$$

Subjected to:

$$\sum_j x_{ij} = 1 \textit{ for all } i; \quad (2)$$

$$\sum_j x_{ij} = 1 \textit{ for all } j; \quad (3)$$

x_{ij} = 1 if facility i is assigned to location j.

= 0 otherwise.

The gap of preliminary model and the developed model to fill it up

As it is obvious in preliminary mathematical model, there is no notation considering number of items (materials) transported from origin facility to the destination facility, whereas the model adopts the cost of transporting per unit distance by notation f_{ij}. The notation f_{ij} represents the cost per unit distance and varies from any unit to the next one; in other word, depended on the specifications of material the cost varies e.g. the cost of transporting a light item like pen will be different from that of heavy like refrigerator. This notation does not care about the number of units and lonely considers the type of unit to be transported. To fill up this gap, the study proposes new notation of n_{ip} that indicates the number of units transporting from facility i to facility p. Hence, there will be new matrix showing the number of units.

In addition, the study believes one more matrix composed of number of barriers between origin and destination locations can make the model more sensitive to the costs resulted from the objective function. Common sense says that the more barriers between locations can make the transportation more costly. To construct this matrix, the study assumes that there is an inspector having some idea of number of barriers between location j (origin) and q (destination). Meanwhile, any kind of obstacles making delay in transportation of items can be considered as barriers. Hence, the more barriers the more costly transport. The study proposes the notation b_{jq} indicating the number of barriers existing between origin and destination locations.

Moreover, the study strongly believes that differentiating between vertical and horizontal interactions in terms of flows (f_{ip}), distances (d_{jq}) and barriers (b_{jq}) can make the model clearer. This is because of their different costs can require to be considered separately. The study represents the vertical and horizontal notations using index V and H respectively.

So, the new developed model with new notations of N and B and same constraint is as:

A = | a_{ij} |, is the fixed cost matrix where a_{ij} is the fixed cost of installing facility i at location j.

F = | f_{ij} |, is the cost of flows matrix where f_{ij} is the cost per unit distance of transporting the material from facility i to facility j including vertical (v) and horizontal (h) interactions.

D = | d_{ij} |, is the distance matrix where d_{ij} is the distance from location i to location j including vertical (v) and horizontal (h) interactions.

N = | n_{ij} |, is the volume matrix where n_{ij} is the number of items transported from facility i to j.

B = | b_{ij} |, is the barriers matrix where b_{ij} is the number of barriers with which is faced between location i and j including vertical (v) and horizontal (h) interactions.

With these definitions new Facility Layout Problem is:

Minimize: $$\sum_i\sum_j a_{ij}.x_{ij} + \sum_i\sum_j\sum_p\sum_q (f^v_{ip}.d^v_{jq}.b^v_{jq} + f^h_{ip}.d^h_{jq}.b^h_{jq})\, n_{ip}.x_{ij}.x_{pq} \qquad (4)$$

According to the constraints (already given), each of facilities can be assigned to the one location lonely and vice versa.

Numerical case study and input data

According to (Wang, Hu and Ku, 2005), the problem is based on a 15 department 3 floor facility with 6 existing (or potential) lifts. The floor areas for various floors are 100 sq. units. The department area data are given in as:

Table 1: Department area data according to (Wang, Hu and Ku, 2005)

Department no	**1**	**2**	**3**	**4**	**5**
Area	12	7	6	5	7
Departments no	**6**	**7**	**8**	**9**	**10**
Area	22	22	13	7	22
Departments no	**11**	**12**	**13**	**14**	**15**
Area	9	13	4	17	25

The cost for the vertical and horizon movement for a unit distance is assumed to be \$5.00 & \$1.00 respectively for all pair of departments. The initial cost of layout equals \$281,702. Thus, the initial cost for allocation of a department to any floor is assumed to be same given by:

Initial cost = [fixed cost/ no of departments] = \$281,702 / 15 = \$ 18780.

The linear floor transport cost coefficient is assumed to be 1.

Due to the new added notations, there is a need to have input data for volumes and barriers. Hence, we add new assumptions to have these data in our numerical case study. The study assumes the following input data for department's flows. In addition, we assumes that there are 10, 20, 15 and 30 barriers between (4, 3), (10, 4), (12, 10) and (14, 12) pairs of departments respectively (for both vertical and horizontal interactions). And the rest of each pair of departments is assumed having no barriers.

The flow (volume) matrix is assumed as:

0	0	0	0	0	0	0	0	0	0	0	0	0	0	240
120	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	600	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	600	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	300	0
0	0	0	0	0	0	0	240	0	0	0	0	0	0	0
0	0	0	0	0	0	0	240	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	240
0	0	0	0	0	0	0	0	0	300	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	300	0	0	0
0	0	0	0	0	0	240	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	300
0	0	0	0	0	0	240	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	300	0	0	0
0	20	50	0	50	80	0	0	50	0	20	0	10	0	0

Model Verification and Validation

At the following Table 2, the result of case study has been given and compared with two previous studies result. As it was mentioned, study assumes that there are 10, 20, 15 and 30 barriers between (4,3), (10,4), (12,10) and (14,12) pair of departments respectively. Each of these pair's farness will be costly, because number of barriers and items has direct relationship with the cost of transportation. This implies the farer pairs will make the more costly transportation. Hence, the closer the pairs, the more cost-effective result.

Comparing the results before and after adding new notations of n_{ip} (number of items being transported from facility i to p), b_{jq} (barriers between location j and q) and their input data to the case study, indicates that the result of new extended model with added new notations (which both make more transportation costs) make sense, because after putting them in preliminary mathematical model and making the new extended one, the given departments (3, 4, 10, 12 and 14) came closer to each other. As it can be seen at the following Table 2, all pairs of departments having barriers between each other are in same floor based on the results of new developed model while they were in different ones already. In other word, the multi-floor facility layout problem has been improved using new extended mathematical model. Thus, the results are enough logic to validate the submitted mathematical model.

Table 2: Comparison of new extended model result with two previous studies (Sahu, Raizada and Agiwal, "A Genetic Algorithm to Multi-Floor Facility Layout Problem") and (Lee, Roh and Jeong, 2005)

Department no	**1**	**2**	**3**	**4**	**5**
Allocated on floor (preliminary model)	2	2	2	2	1
Allocated on floor (multiple model)	2	2	2	2	0
Allocated on floor (Study extended model)	1	1	2	2	0
Department no	**6**	**7**	**8**	**9**	**10**
Allocated on floor (preliminary model)	1	0	0	2	2
Allocated on floor (multiple model)	1	1	1	2	2
Allocated on floor (Study extended model)	1	1	1	2	2
Department no	**11**	**12**	**13**	**14**	**15**
Allocated on floor (preliminary model)	0	1	0	1	0
Allocated on floor (multiple model)	2	0	0	0	0
Allocated on floor (Study extended model)	2	2	0	2	0

Summary

In this study we developed a preliminary mathematical model of multi-floor layout problems with the goal to minimize the total fixed cost & inter-floor interaction cost. The objective of the study was to achieve an extended model by adding two new notations of nip and b_{jq} representing the number of items going from facility i to facility p and number of barriers between location j and q, respectively. As well as, the study put both vertical and horizontal interactions separately in terms of flows (f_{ip}), distances (d_{jq}) and barriers (b_{jq}) because of different costs of these two types of movements. Then, a numerical case study already solved by preliminary mathematical model was applied to validate this developed model. The numerical case study developed by two new added notations was solved by extending genetic search codes of preliminary mathematical model. Finally Computational presented results indicated that this model solves the multi-floor layout problems more cost-effective than the previous ones. The results also indicated that extended model minimizes the cost of layout problem through enclosing those pairs of departments between which have barriers. According to the reported result, the departments 3, 4, 10, 12 and 14 were enclosed and allocated in same floor (floor number 2) that make lower cost and indicates the improvement of layout resulted by extended model.

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