Proceedings of the 1985 Winter Simulation Conference
D. Gantz, G. Blais, S. Solomon (eds.)

MULTILEVEL FACILITY LAYOUT

Keebom Kang, Ramon Rodriguez and Oscar Adaniya
Department of Industrial Engineering
University of Miami
Coral Gables, Florida 33124

ABSTRACT

This paper presents an approach to solve multilevel facility layout problems when the traveling times between departments are nonlinear. The objective is to obtain a solution that minimizes the total expected cost of movement, such that all the space requirements are satisfied. Due to the complexity of the problem a heuristic is developed so that a good solution can be obtained in an acceptable computational time.

INTRODUCTION

The layout problem has been under study for several decades, and until recent years the multilevel case has been ignored. Since the accessability and speed of computers have tremendously increased, new methods are now available.

Hales (1) classified the different approaches used for layout planning as follows:

1. Bubble diagramming.
2. Systematic layout planning, proposed by Muther (2).
3. Scoring techniques, i.e. SCORE/CORELAP by Moore (3).
4. Clustering techniques by Scriabin and Vergin (4).
5. Layout algorithms: The algorithms can be classified as construction routines and improvement routines. Among the well known improvement routines are CRAFT (5) and COFAD (6); for the construction routines there are CORELAP (7), ALDEP (8). The last routine is multi-dimensional. Among the operations research techniques used are the transportation algorithm, branch-and-bound, graph-theory, and quadratic assignment algorithms.

Some of these techniques can be used in multilevel layout, and the method proposed in this paper is an example. Multilevel problems are more difficult since the traveling times between departments are a function of the location (floor) elevator dispatching strategy, and traffic demands. The traffic demands are dependent upon the layout, and the changes in the traffic demand cause the changes in the travel time. Simulation is used to estimate the travel time.

ANALYSIS OF THE PROBLEM

The problem structure is divided into five parts: the building size, shape and restrictions, movement characteristics, inter-departmental flow, objective function, and elevator operating system. To solve the problem the following information has to be provided by the analyst: number of departments, space required by each department, building dimensions for each floor, size of the modules (each department has an integer number of modules of an equal size), space constraints (elevators, stairways, idles, ...), location of elevators with their characteristics, such as number, capacity, speed, and dispatching strategy.

The travel time between two departments on the same floor is the time it takes to go from one department centroid to another department centroid using rectinlinear travel. However, the vertical travel using elevators creates a waiting time situation. The travel time between two departments on different floors consists of travel from one department centroid to the closest elevator cluster, plus the waiting time for the elevator, plus elevator riding time, plus the travel time from the elevator to the other department. This indirect routing causes nonlinearity of the travel time.

Foulds and Giffin (9) have approached this problem using a fixed-charge model to obtain the expected travel time between locations:

$$t(i,j) = a + b * ABS(F(i) - F(j))$$

where t(i,j) is the travel time from the department i to the department j, and F(k) is the floor in which the department k is located. The assumptions of this model are: constant waiting time, constant intermediate-floor stoppage times, constant travel time between floors, and the vertical travel time dominates the total travel, i.e., the horizontal travel time is negligible. These assumptions are not appropriate for our purpose.

In many cases, the inter-floor travel time must be provided by the user [e.g. SPACECRAFT by Johnson (10)]. However, the estimation of elevator waiting and riding time is a complicated queueing problem. The waiting and riding time depends on the characteristics of the elevator itself, the traffic demands at each floor, and the elevator dispatching strategy [Powell(11)].

The significance of the dispatching strategy can be explained with a simple example [Games(12)]. If poor or no dispatching strategy is applied to a multiple elevator system, two or more elevators traverse the service area as a group, separated at most, by a few floors ("bunching"). Then the passenger waiting time is almost the same as in a single elevator system. Ideally, if n elevators are evenly spaced the expected waiting time would be 1/n of the single elevator case.

The literature in elevator behavior or operating system is limited. The emphasis of many papers in elevator field is on the analysis of up-peak or down-peak traffic, ignoring inter-floor travel [e.g. Browne and Kelly (13)]. Gamse and Newell (14 & 15) developed an approximations of elevator round trip time. Games (12) used simulation to develop a method to prevent bunching. Powell (16) developed a dispatching strategy called Adaptive Traffic Management (ATM) for Westinghouse. However, only the simplified strategy of ATM was reported.

A good dispatching strategy is very important to develop a good layout. A poor operating strategy results in inefficient layout, and poor layout causes high utilization of elevators, which, in turn, increases the total vertical travel time. Elevator travel time is dominated by the time spent at stops rather than vertical movement itself. A good strategy can reduce unnecessary stops, which will decrease the total travel time. The simulation experiments show that the dispatching strategy is more sensitive than the traffic condition.

In this paper, to achieve the initial layout, simulation is used to estimate the travel time from one floor to every other floor. As an example, consider a 10-story building with 2 elevators. Arrival rate for each floor follows the Poisson process with interarrival time of 10 seconds. Each elevator is operated independently, without any control. (Dispatching strategies are being studied and a good strategy will be selected and applied in this step.) The vertical travel from one floor to the adjacent floor is 1 second, and each stop takes 12 seconds. A passenger on a certain floor has the equal probability of going to any other floor.

Using SIMAN (17), the matrix of Fig. 1 is obtained as estimates of travel time from one floor to every other floor including waiting time, which will be used as initial estimates of vertical travel times. Then the matrix will be updated with the improvement of the layout.

PROCEDURES

One of the input for this program is the number of trips per unit time required between all the departments. This is an asymmetrical matrix with the diagonal elements equal to zero. The upper triangle part of the matrix reflects the forward trips and the lower triangle of the matrix signify the backward trips. For the purpose of having a qualitative relationship between departments, this traveling matrix is folded, therefore we end with an upper triangle matrix.

It can be said that two departments, I and J, have a stronger relationship than departments I and K, if the value I, J in the relationship matrix is larger than the value I, K.

The user of this multi-floor facility layout program has three options. The first is to provide a feasible initial layout. The second alternative is to use the procedure of ALDEP (8). ALDEP generates random layouts; it places the first department in the upper left corner of the layout and extends it downward using a sweep width provided by the user. The next department to be located has a strong relationship with the previous one. Ties are randomly broken. This procedure can generate as many layouts as requested by the user. Each layout is evaluated using the sum of an approximation of the expected travel times between all department centroids, using rectilinear distances, multiplied by the number of trips required by the departments. The third approach for obtaining an initial layout is based on mathematical taxonomy. Based on the information provided by the analyst, a feasible layout is obtained using cluster analysis, Gordon (18). There are at least as many clusters as floors available, restricted to the availability of area, therefore more than one cluster may be assigned to any specific floor. The objective of this cluster assignment is to minimize the product of the number of trips by the expected travel time. Departments on each floor are placed using an approach similar to ALDEP, then this partial solution is improved via a heuristic. This is done for each floor and then the same improvement heuristic is used between floors using the initial estimators for vertical travel time.

The vertical travel time is now reevaluated based on the traffic demand from the results of the initial layout. Total expected cost of movement is calculated. Then the user has an option to repeat the improvement procedure until an acceptable solution is found.

CONCLUSIONS

In multilevel layout problems, the use of elevators creates nonlinear travel time between departments. This nonlinearity increases the complexity of the

f\t	1	2	3	4	5	6	7	8	9	10
1	.00	58.50	69.15	65.21	68.94	72.14	71.05	72.19	76.76	80.61
2	29.91	.00	64.44	72.09	69.65	68.90	68.11	70.44	74.84	74.77
3	40.61	35.31	.00	68.08	70.17	61.53	64.84	76.09	65.92	66.81
4	51.75	47.61	36.37	.00	69.35	66.07	72.53	68.47	67.65	78.76
5	65.25	70.77	63.07	45.17	.00	74.29	78.48	71.16	72.89	69.47
6	78.40	60.57	62.13	69.62	64.77	.00	54.49	59.57	58.20	66.39
7	89.54	77.43	61.28	67.53	59.93	67.87	.00	48.86	46.26	52.42
8	78.26	81.69	83.04	71.90	73.32	66.69	59.22	.00	27.88	34.96
9	94.62	85.09	83.94	80.65	74.39	73.94	69.76	64.24	.00	30.38
10	111.10	108.99	107.48	96.86	97.20	71.24	84.81	94.92	83.76	.00

Fig. 1: Estimated Travel Time from Floor to Floor Including Waiting Time (unit:sec)

layout. The elevator dispatching strategy is important. A good layout will decrease the utilization of elevators, and a good dispatching strategy will result in a reduction of the total expected movement cost.

Currently, we are experimenting this methodology with serveral other methods. The computational results will be deferred to our subsequent paper.

REFERENCES

1. Hales, H. Lee, Computer-Aided Facilities Planning, Marcel Dekker, Inc., New York, 1984.
2. Muther, R., Systematic Layout Planning, Second Edition, Cahners Books, Boston, 1973.
3. Moore, J. M., "Computer Program Evaluates Plant Layout Alternatives," Industrial Engineering, 19, 3, 1976.
4. Scriabin, M. and R. C. Vergin, "A Cluster-Analytic Approach to Facility Layout," Management Science, Vol. 31, No. 1, Jan. 1985, pp. 33-49.
5. Armour, G. C. and E. S. Buffa, "A Heuristic Algorithm and Simulation Approach to Relative Location of Facilities," Management Science, Vol. 9, No. 2, Oct. 1963, pp. 294-309.
6. Tomkins, J. A. and J. A. White, Facilities Planning, J. Wiley, New York, 1984.
7. Lee, R. C. and J. M. Moore, "CORELAP - Computerized Relationship Layout Planning," Journal of Industrial Engineering, Vol. 18, No. 3, March 1967, pp. 195-200.
8. Seehof, J. M. and W. O. Evans, "Automated Layout Design Program," Journal of Industrial Engineering, Vol. 18, 1967, pp. 690-695.
9. Foulds, L. R. and J. W. Giffin, "A Graph-Theoretic Heuristic for Multi-Floor Building Layout," 1984 Annual International Industrial Engineering Conference Proceedings.
10. Johnson, R. V., "Spacecraft for Multi-Floor Layout Planning," Management Science, Vol. 28, No. 4, April 1982, pp. 407-417.
11. Powell, B.A., "The Role of Computer Simulation in the Development of a New Elevator Roduct," Proceedings of the 1984 Winter Simulation Conference, 1984, pp.445-450.
12. Games, B. A Simulation of an Elevator System for a Merate Height Building, University of California, Berkeley, UCB-ITS-SR-76-5, 1976.
13. Browne, J. J. and J. J. Kelly, "Simulation of Elevator System for World's Tallest Builing," Transportation Science, 2, 1968, pp.35-56.
14. Games, B. and G. F. Newell, "An Analysis of Elevator Operation in Moderate Height Building - I: A Single Elevator," Trasportation Research, 16B, 1982, pp.303-319
15. Games, B. and G.F. Newell, "An analysis of Elevator Operation in Moderate Height Building - II," Transportation Research, 16,4, 1982, pp.321-335.
16. Powell, B.A., "Mathematical Modeling of Elevator Systems," from Case Studies in Mathematical Modeling, edited by Boyce, W.E., Pitman Advanced Publishing Limited, London, 1981, pp.18-53.
17. Pegden, C.D., Introduction to SIMAN, System Modeling Corp., Station College, PA, 1984.
18. Gordon, A.D. Classification: Methods for the exploratory analysis of multivariate data, Chapman and Hall, London, 1980.

KEEBOM KANG is an Assistant Professor of Industrial Engineering at the University of Miami. He received his Ph.D. from the School of Industrial Engineering, Purdue University. His areas of interest are statistical analysis of simulation output analysis, and stochastic modeling.

RAMON RODRIGUEZ is an Assisntant Professor of Industial Engineering at the University of Miami. He received his Ph.D. from the School of Industrial and Systems Engineering, Georgia Tech. His areas of interest are production and distribution.

OSCAR ADANIYA is an Assistant Professor of Industrial Engineering at the University of Miami. He received his Ph.D. from the School of Industrial and Systems Engineering, Georgia Tech. His area of interest is operations research.

Department of Industrial Engineering
Univerisity of Miami
Coral Gables, Florida 33124
(305) 284-2344