A study on the Facilities Layout Algorithm applying Multidimensional scaling

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Abstract

The Facilities layout problem is a type of combinational optimization problem, and facilities should be allocated according to the desirability of closeness among them. Designing the layout, modern heuristics such as SA, GA have been adopted for the complexity of the problem. On the other hand, Multidimensional Scaling (MDS) has also been adopted. It is a useful mathematical tool that outputs a relationship diagram corresponding to the desirability of closeness. Therefore, by attaching the areas and nodes of the relationship diagram, a facilities layout corresponding to closeness relationships is obtained. In this paper, a facilities layout algorithm that combines MDS with Boundary method is proposed, and its effectiveness is proven.

1. Introduction

The facilities layout problem is one of the combinational optimization problems, whose objective is to allocate facilities according to desirability of closeness, i.e. due to flows of materials and relationships among facilities. In addition to desirability of closeness, the areas of facilities are also constraints. To solve the problem, those constraints must be satisfied. Layout designers need to use modern heuristics such as SA, GA for the complexity of the problem in designing.

On the other hand, Multidimensional Scaling (MDS) is a widely-used mathematical tool in marketing analysis and psychometry. The input of MDS is the degree of similarity (or dissimilarity) between objects, whereas the output is a relationship diagram corresponding to the degree of similarity (or dissimilarity). Thus a relationship diagram that shows relative location of facilities is obtained by using desirability of closeness as input of MDS, and the corresponding layout is obtained by attaching areas to nodes in the relationship diagram. But it is important to note that the difference between the location of facilities and the node in the relationship diagram generated from MDS results by attaching area to node. There are also studies about the application of MDS to the facilities layout problem [1] [2]. In [1], all the facilities are treated with equal departmental areas and no algorithmic procedure is provided for generating a layout from a relationship diagram. In [2], both equal and unequal areas can be used, but the output is only a bay-structured layout. Thus in some cases, the shape of the facilities may be unpractical.

In this paper, we present a new facilities layout algorithm using MDS together with the Boundary method, and prove the effectiveness of the algorithm though experimental result.

2. Assumptions

In this paper, we focus on the single-floor facility layout problem under the assumptions described as follows. 1) The information of area and number of facility is given. 2) Facilities are rectangular. 3) The building is rectangular. Besides, the objective function was limited to $\sum \mathrm{DI}$, which means Distance-Intensity and is commonly used as an objective function of facilities layout problem.

3. Multidimensional scaling

We employed Kruscal's Method which uses the formulation called "Stress" as MDS. Stress indicates the goodness-of-fit of each node in the diagram and its formula is described below.

$$S = \sqrt{\frac{\sum_{i<j}\left(d_{ij} - \hat{d}_{ij}\right)^2}{\sum_{i<j} d_{ij}^{\ 2}}} \qquad (1)$$

In equation (1), d_{ij} denotes the distance between node i and node j, $\hat{d}_{ij}$ denotes the distance between ideal node i and node j corresponding to input. The ideal relative location can be obtained by finding the coordinates of the nodes (facilities) that minimize the value of Stress.

For the facilities layout problem, the idea of closeness rating and flow of materials have been used in many heuristics. Those ideas of desirability of closeness can be associated with the notion of similarity (or dissimilarity). Therefore a relationship diagram corresponding to desirability of closeness can be obtained by Kruscal's Method.

4. Boundary method

The boundary method is a VLSI floorplan method developed by Sawa et al.[3]. In Boundary method, integer values of "code" and "order" indicating point and order to be allocated are assigned to every facility. The "Boundary" is composed of x-axis, y-axis, and the other facilities already placed. Each facility is allocated according to the code and order assigned to each facility. Fig1 shows the procedure of the Boundary method.

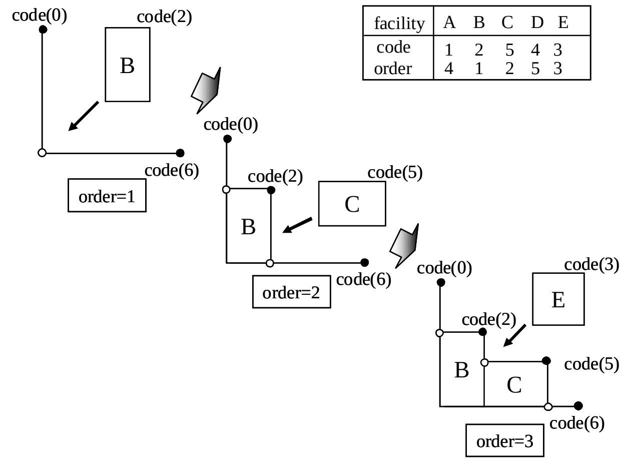

Fig.1 Boundary method

5. Proposed Algorithm

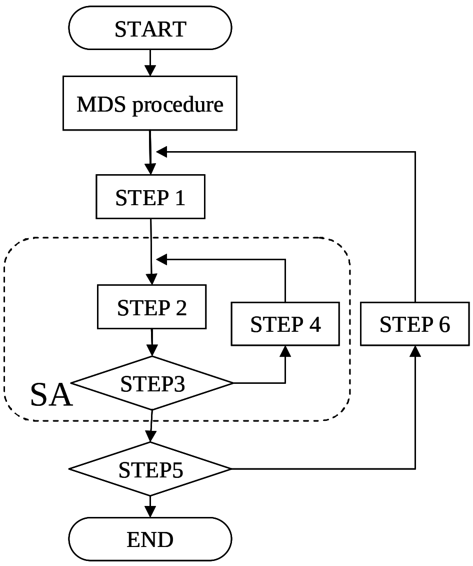

Fig2. Flowchart of proposed procedure

5.1 Layout procedure ~STEP1 and STEP2~

Code and order indicate the relative location of allocated facilities in the layout, as well as the relationship diagram. Thus, code and order can be generated from the relationship diagram. Assuming that the x-axis denotes the diagonal of the final layout, order is determined by ascending order of the x-coordinate and code is determined by descending order of the y-coordinate. In Step2, each facility is allocated according to the code and order generated in Step1.

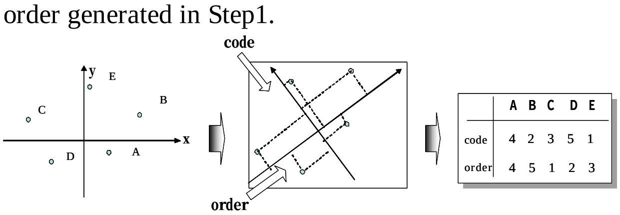

Fig3. Code and order generating from relative diagram

5.2 Search procedure~STEP3 and STEP4~

In the case where the aspect ratio of the facility can be modified, Step3 and 4 are performed. Step3 and 4 are a search algorithm for aspect ratio, which is changed by Simulated Annealing (SA) procedure without changing the code (Step3) and ordered until the end condition of SA is satisfied (Step4).

5.3 Search procedure2~STEP5 and STEP6~

The output of MDS has several characteristics, and the ones described below are used to change the layout in this paper.
(A)The points (nodes) output from MDS can be rotated about the origin.
(B) The points (nodes) output from MDS can be symmetrically displaced about the x-axis (or y-axis).
Some different layouts can be generated by (A) and (B) without changing the value of Stress. First, rotate the diagram by 1° until the different code or order is generated. If one different code or order is generated, each facility can be allocated according to those and the layout is evaluated by $\sum$DI. As often as a different code or order is generated, (A) is repeated until the angle reaches 360°. When the angle of rotation reaches 360°, (B) is performed. After symmetric displacement, (A) is performed once again until 360°. If the second rotation is finished, the search algorithm is over.

6. COMPUTATIONAL RESULTS

We conducted an experiment to examine the effectiveness of the proposed algorithm. The experiment has 8 facilities, whose flows of material are shown in Table.1, which is used in [1]. Table.2 shows the output of MDS and Fig.4 shows the relationship diagram.

Table.1 Flow of material

From/To	1	2	3	4	5	6	7	8
1	-							
2	10	-						
3	5	360	-					
4	90	120	350	-				
5	370	40	110	190	-			
6	135	115	40	70	10	-		
7	125	45	20	50	40	50	-	
8	0	120	200	10	10	20	20	-

Table.2 Output of MDS

Facility	X-cordinate	Y-cordinate
1	1.187	1.881
2	1.758	0.360
3	0.668	0.503
4	1.274	0.860
5	0.422	1.269
6	2.195	1.106
7	1.844	2.152
8	1.273	-0.240

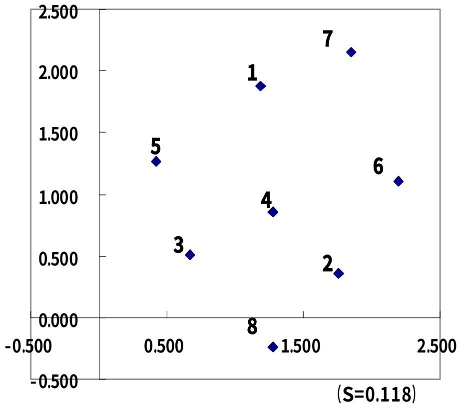

Fig.4 Relationship diagram

In this experiment, the layout generated by the proposed algorithm is shown in Fig.5, and the value of $\sum$DI was 34,796.

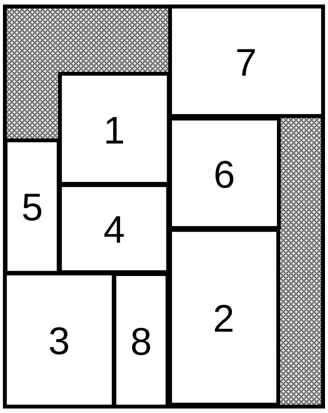

Fig.5 The resulting layout of experiment

The layout generated by the proposed algorithm is the so-called "non-slicing structure". Comparing Fig.4 and Fig.5, it is obvious that the layout contains the relative location of diagram Fig.4.

The hitherto study [2] was applied only to the so-called "slicing layout" problem, wheras the proposed algorithm generates "non-slicing layout". In the case of slicing layout, the layout may violate constraints of aspect ratio, which can be unpractical because of constraints of equipments depending on area information.

7. Conclusion

In this paper, a new layout algorithm combining MDS with Boundary method was proposed and an experiment was conducted to examine its effectiveness. The layout generated by the proposed algorithm holds the information of relationship diagram from MDS.

References

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