

A Group Decision Model for Selecting Facility Layout Alternatives

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Abstract. Facility layout problems (FLP) are usually treated as design problems. Lack of systematic and objective tools to compare design alternatives results in decision-making to be dominated by the experiences or preferences of designers or managers. To increase objectivity and effectiveness of decision-making in facility layout selections, a decision support model is necessary. We proposed a decision model, which regards the FLP as a multi-attribute decision making (MADM) problem. We identify sets of attributes crucial to layout selections, quantitative indices for attributes, and methods of ranking alternatives. For a requested facility layout design, many alternatives could be developed. The enormous alternatives, various attributes, and comparison of assigned qualitative values to each attribute, form a complicated decision problem. To treat facility layout selection problems as a MADM problem, we used the linear assignment method to rank before selecting those high ranks as candidates. We modelled the application of the Nemawashi process to simulate the group decision-making procedure and help efficiently achieve agreement. The electronics manufacturing service (EMS) industry has frequent and costly facility layout modifications. Our models are helpful to them. We use an electronics manufacturing service company to illustrate the decision-making process of our models.

Keywords: Multiattribute Decision Making, Group Decision, Facility Layout Problems, Linear Programming, Nemawashi Process

1. INTRODUCTION

1.1 Facility Layouts

Sthahl's study, as cited in (Alberto *et al.*, 1989), regards facility layouts as the arrangement of workspace,

which in general terms smoothes the way to access facilities that have strong interaction. The aims are similar whether the organizations are services or manufacturer. Facilities are of crucial importance to organizations. Usually they represent the largest and most expensive assets of an organization. This definition gives a macroscopic

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view of facility layouts. It reveals that facility layout planning is a work to arrange closely related facilities together. The goals are similar for manufacturer and service industries. Moreover, the work is so important for it stands for lots of asset inputs in every company. Another definition from Evans (1994) gives a more specific picture of facility layout and its functions. In Evans' opinion, facility layouts refer to the specific arrangement of the physical facilities. The layout affects material flow, handling and maintenance costs, equipment use, productivity, production flexibility, management effectiveness, and even employee morale. Therefore, we catch the great effect of facility layouts on arranging facilities. Reid and Sanders (2002) proposed that facility layout planning is about deciding the best physical arrangement of resources consuming space within a facility. Resources might include a desk, a work center, a cabinet, a person, an entire office, or a department. Stevenson (2002) pointed out that facility layouts are the configuration of departments, work centers, and equipment, with particular emphasis on movement of work (customers or materials) through the system.

From the definitions mentioned above, we may have a clear picture of facility layouts. Basically, facility layouts, or facility layout planning, are to arrange limited space in an organization for the various use of personnel, equipments, or departments. This arrangement has great influence on the activities in the organization.

1.2 Facility Layout Problems in EMS Industry

The EMS (Electronics Manufacturing Service) industry provides OEMs (Original Equipment Manufacturers) all kinds of electronic products and customized products with lower cost and faster time-to-market. When OEMs come up with a great product idea, EMS companies help to design it and provide critical subassemblies to make sure it meets the objectives of performance, cost, and size. The EMS companies test the product, prepare it for manufacturing and take it to full production. Then they box the product, ship it, and install it. Once in use, the EMS companies provide end-customer service and technical support. If repairs are required, EMS companies make the fix.

In order to achieve customer satisfaction, EMS companies must be good at jobs, such as global logistics, mass production, cost control, ability to design, and flexibility. More and more, leading OEMs rely on EMS providers to assemble their products. The main drivers pushing OEMs to outsource include continuous market pressures to shorten time-to-market, enhance asset use, and master the complexity of process technologies. In essence, outsourcing enables OEMs to focus on their core abilities, which include research, development, sales, and marketing.

To maintain a long-term and stable partnership with OEMs, EMS companies undertake a number of burdens unfavorably. Some burdens are related to facility layout. Ordinarily, an EMS company simultaneously offers manufacture service to several OEMs. Because of product secrets, quality assurance, and other management concerns, almost all OEMs request private production areas. Satisfying leading OEMs with private production areas divides the whole facility layout into separate parts. Facility layout modifications consequently occur for the cooperation growth or decline between the EMS companies and OEMs.

In addition to the cooperation, the business status of each OEM modifies the facility layout of EMS. This status directly affects orders to EMS partners. This means the required production capacities of EMS companies are dynamic. Because the production areas and equipment are allocated to certain OEMs, capacity variations from any OEM can result in facility layout modifications. Modifications include enlarging production areas, adding equipment, or allocating space and equipment to other OEMs.

A similar situation arises when new products are introduced into an OEM's production area. New product introductions not only demand extra capacity, they may also require special equipment. This special equipment may need revised infrastructures, such as water drains, constant temperatures, or humidity control. Adding this equipment into production lines require further facility layout modifications.

Company U, a worldwide EMS firm with headquarters in Taiwan, is experiencing costly and frequent facility layout modifications. The facility layout modification evidence of two manufacturing sites in Taiwan is summarized in Table 1. This summary shows the real condition of facility layout modifications and highlights the seriousness of this problem.

1.3 Motivation and Objectives

The evidence of frequent layout modifications in the EMS industry was unavoidably observed in practice. Real facility layout planning is as follows: First, design several alternatives in a short time. New layout designs do not need to be perfect, but must be quick and flexible. Second, select one of the alternatives. Third, quickly execute the layout modifications. Under this scenario, a good tool for evaluating layout alternatives is critical for making decisions and controlling modification costs. Good decisions may result in fewer layout modifications. Good decisions can decrease the expense of each layout modification. The attempt to decrease the facility layout costs in this scenario increases motivation to develop a decision support model for selecting among alternative facility layouts. This model is applicable to general facility layout alternative selection problems. It is not limited to EMS industry.

Table 1. Facility layout modification summary of company U in 2003

Facility layout modification evidences in 2003				
Item	Month	Specification	Layout type	Cost (approx.) NTD.
3-1	1	Re-layout for adding one SMT line (PD2)	Production area	180 thousand
3-2	2	Waste solvent area(Plant 1 to Plant 2)	Production area	350 thousand
3-3	3	Re-layout for adding one SMT line (PD2)	Production area	180 thousand
3-4	3	Re-layout for Symbol production area (From 3F to 4F)	Production area	1 million
3-5	3	New production BTM at NK Plant(PD1)	Production area	200 thousand
3-6	3	New production EMS at NK Plant	Production area	85 thousand
3-7	3	New production area(PD7) in NK Plant 5F	Production area, office	1.2 million
3-8	4	Re-layout for Notebook production line (PD4)	Production area	1 million
3-9	4	Remove office (in production area) for production line (PD4)	Production area	120 thousand
3-10	4	Office relayout(4F to 5F)	Office	7 million
3-11	4	Re-layout for BTM auto production line(PD1)	Production area	1.1 million
3-12	4	Re-layout for PD1 and EQ office	Office	170 thousand
3-13	5	Re-layout for new production line(PD1,ALPS/BTM)	Production area	1.3 million
3-14	5	Remove IQC office in warehouse(PD6)	Office	200 thousand
3-15	6	Burn-in chamber (From Plant NK 2F to Plant NK 3F)	Production area	30 thousand
3-16	6	Re-layout for PD7 NK Plant (Enlargement)	Production area	1.2 million
3-17	8	Re-layout for Notebook production line (PD4)	Production area	10 thousand
3-18	8	Re-layout for adding one ICT and one Press(PD4)	Production area	NA
3-19	9	PD1 Line-side stock area building	Production area	60 thousand
3-20	12	Switch a SMT line from PD2 to PD5, NK Plant	Production area	200 thousand
3-21	12	RD office movement(Plant 1 A building to BC building)	Office, Lab.	5.5 million
3-22	12	New production area for LCDTV	Production area	7.5 million

Remark: NA means the data is Not Available.

Usually, lack of a systematic and objective tools cause the decision-making to be dominated by the experiences and preferences of top managers. Therefore, the decision-making is subjective and unstructured. Since facility layouts affect so many departments and personnel, the decisions need to be made by a group of decision makers, not a single individual. Decision-making will require much time. As a result, we tried to construct a decision support model to provide necessary information to decision makers. The model gives decision makers qualitative data for making decisions.

After examining the shortcomings in the current decision-making process, we set these goals for developing a decision support model:

1. Objective decision-making: the model should be made according to objective data or figures.
2. Systematic decision making process: the model should offer a structured process, to decide attributes, compare alternatives in each attributes, and make final decision according to a particular selection rule.
3. Time saving: the model should be capable of shorten the decision making time.
4. Overall approval: the model should be helpful to facilitate the generation of consensus of multiple decision makers.

To construct a model that satisfied these four goals, we reviewed the attributes and qualitative indices used to select facility layout alternatives. Then we reviewed alternative ranking methods in each decision-making category. After considering the characteristics of a facility lay-

out selection problem, we construct a decision support model for selecting facility layout alternatives. We evaluate the model for scenarios using a single decision maker and those with multiple decision makers. Considering these four goals, the supporting model is expected to improving the quality of decisions selecting among layout alternatives.

2. LITERATURE REVIEW

Facility layout problems are often treated as design problems. Therefore, many studies discussed optimization for a single objective, such as minimum equipment investment cost, maximum space use, and minimum material handling cost. For facility layout selections or decision-makings, all objectives should be considered.

To create a decision support model for facility layout selection problems, we reviewed the attributes to be considered when first making a decision. A quantitative index for attributes may be needed to rank them among alternatives. A method that ranks alternatives is necessary for decision-making.

Lin and Sharp's study (1999b), show that there are few studies of facility layout selection. Most studies are of facility layout design problems. We found only a few papers proposed attributes for facility layout selection. Even fewer papers mentioned quantitative indices and methods for selecting among alternatives. Here, we summarize the literature of attributes, quantitative indices, and alternative ranking methods.

Table 2. Attributes set with three groups, seven classes and 18 attributes

The structured criterion set for plant layout evaluation						
Cost		Flow			Environment	
Non- inventory	Inventory	Space relationship	Material flow	Robustness and flexibility	Surrounding	Environment quality
Initial cost: Land Building Production Machinery Material Handling equipment	Raw materials inventory holding cost WIP inventory holding cost	Clearness Space sufficiency and utilization	Aisle Distance and volume density	Robustness of equipment capacity Building expansion	Topography and topology Community environment	Human-related safety Worker-related comfort Property- related security Access for maintenance
Annual operation and maintenance cost: Labor Utility Maintenance	Finished goods inventory holding cost					
Future salvage value						

Source: Lin *et al.*, 1999

2.1 Attributes for Facility Layout Selections

The first problem of making a selection decision is the attributes needed to differentiate all alternatives.

For judging facility layout alternatives, Muther (1973) proposed another set of detailed attributes. The attributes were classified into 20 groups:

1. Ease of future expansion.
2. Adaptability and versatility.
3. Flexibility of layout.
4. Flow or movement effectiveness.
5. Material handling effectiveness.
6. Storage effectiveness.
7. Space utilization.
8. Effectiveness of supporting service integration.
9. Safety and housekeeping.
10. Working conditions and employee satisfaction.
11. Ease of supervision and control.
12. Appearance, promotional value, public or community.
13. Quality of product or material.
14. Maintenance problems.
15. Fit with company organization structure.
16. Equipment utilization.
17. Plant security and theft.
18. Utilization of natural conditions, building or surroundings.
19. Ability to meet capacity or requirement.
20. Compatibility with long-range company plan.

Francis *et al.* (1992) specified 13 attributes for ranking facility layout alternatives.

1. Ease of future expansion
2. Flexibility of layout.
3. Material handling effectiveness.
4. Space utilization.
5. Safety and housekeeping.
6. Working conditions.
7. Ease of supervision and control.
8. Appearance, promotional value, public or community relations.
9. Fit with company organization structure.
10. Equipment utilization.
11. Ability to meet capacity or requirement.
12. Investment or capital required.
13. Saving, payout, return and profitability.

Lin and Sharp (1999a) also developed a set of structured attributes for comparison among layout alternatives. They classified 18 attributes into three groups: cost attributes, flow attributes, and environment attributes. These attributes are shown in Table 2. From these three groups of attributes, we learn that attributes cover a huge range from cost, space, material flow, and security to mental impression of facility layouts. The main reason for attribute sets is the enormous and various effects of facility layouts on any organization.

2.2 Qualitative Indices of Attributes

In addition to identify the attributes, another crucial goal of selecting among alternatives is to distinguish the performance of each attribute in each alternative. To show objectively the strength or weakness in each attribute, we

build a qualitative index for each attribute. These indices yield less arbitrary information for decision-making.

To deal with the problem of qualitative indices, Muther (1973) suggested a set of rating code to evaluate the advantage or disadvantage of alternatives in each attribute (Table 3). Each alternative is assigned a code: A, E, I, O, U and X. Each code represents a numerical value. This permits comparison among the alternatives in every attribute.

Table 3. Muther’s rating code

Rating code and values		
Vowel coding	Description of rate	Numerical value
A	Almost perfect (Excellent)	
E	Especially good (Very good)	
I	Important results obtained (Good)	
O	Ordinary results provided (Fair)	
U	Unimportant results (Poor)	
X	Not acceptable	

Lin and Sharp (1999b) also proposed some qualitative indices for his 18 attributes. For the attributes in his cost group, all indices use economic dollar values. Therefore, there is no need for another qualitative index for this cost group. The qualitative indices are required for flow and environment groups.

These qualitative indices attempt to compare alternatives with exact attribute values. When once numerous alternatives and attributes are considered, problems may occur. Assigning the proper Muther (1973) rating to each attribute may be difficult and subjective. Calculating the exact figure of each attribute can be a problem with Lin and Sharps’ (1996b) indices.

2.3 Methods for Ranking Alternatives

The Simple Additive Weighting Method is most often used to rank alternatives. With Muther’s (1973) selection method, decision makers assign weights to attributes. Each alternative can be scored by summing up the multiplications of each attribute’s weight and rating code. With these scores, we certainly rank alternatives and make the selection based on the scores.

Though Lin and Sharp (1993b) developed detailed quantitative indices for each attributes, they ranked alternatives using the Simple Additive Weighting Method. With this method, decision maker assigns weights to attributes, selecting the alternative with the highest score. Since facility layout designs must satisfy various conflicting objectives, various attributes must be considered when judging among alternatives. Therefore, facility layout selection problems can be considered Multiple Attributes Decision Making (MADM) problems. There are many methods for solving MADM problems.

3. CONSTRUCTION OF A GROUP DECISION SUPPORT MODEL FOR FACILITY LAYOUT SELECTION

After investigating the group decision-making process of facility layout selection problems, a MADM model was proposed and applied to the group decision situation. We use a sample to demonstrate our models.

3.1 Group Decision-Making Process of Facility Layout Selection Problems

Facility layout selection problems occur when facility layout designs are requested. In general, company IE engineers are responsible for collecting the requirements of facility layout design from the departments concerned. After classifying and analysing the requirements, IE engineers develop several alternatives. To select potential alternatives from all developed alternatives, IE engineers perform cost estimations and advantage-disadvantage analysis. Candidate alternatives are selected after analysis.

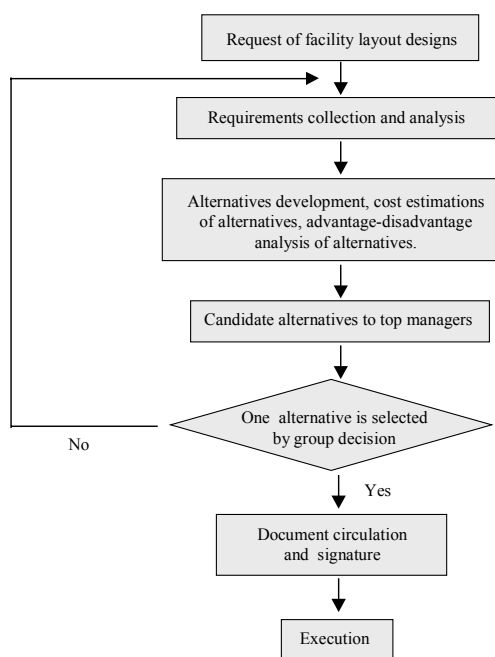


Figure 1. Decision making process of facility layout selections

Since the facility layout selection problems always concern several departments, candidate alternatives are carefully evaluated by the company’s top managers. After negotiation and persuasion, one alternative is finally chosen as the consensus plan. After the decision is made, IE engineers edit a formal document, forwarding it for signature and announcement.

After document circulation is completed, the facility layout can be implemented. If no candidate alternative is

satisfactory, IE engineers then must develop new alternatives. The decision making process of facility layout selection is summarized in Figure 1.

3.2 Linear Assignment Method

Bernardo and Blin (1977) developed the Linear Assignment Method to deal with consumer choice among multi-attributed brands. Compared with other methods in MADM, this method possesses these characteristics (Hwang and Yoon, 1981), the method

1. is based on a set of attribute-wise rankings and a set of attribute weights;
2. features a linear compensatory process for attribute interaction and combination; and
3. inputs ordinal data, not cardinal data, with this method, we do not need to scale qualitative attributes.

3.2.1 Product-attribute matrix

The linear assignment method first defines a product-attribute matrix π as a square ($m \times m$) nonnegative matrix. The elements π_{ik} represent the frequency (or number) of alternative i (A_i) in the k_{th} attribute-wise ranking.

Now, suppose we have three alternatives, A_1, A_2, A_3 , and considers three attributes, X_1, X_2, X_3 . The ranking of alternatives in each attribute is as follows:

Rank	X_1	X_2	X_3
1 _{st}	A_1	A_1	A_2
2 _{nd}	A_2	A_3	A_1
3 _{rd}	A_3	A_2	A_3

(1)

From this, we can create the π matrix:

$$\pi = \begin{matrix} & \begin{matrix} 1_{st} & 2_{nd} & 3_{rd} \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \end{matrix} & \begin{bmatrix} 2 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 2 \end{bmatrix} \end{matrix} \quad (2)$$

And if we weight the attributes, $W = (W_1, W_2, W_3) = (0.2, 0.3, 0.5)$, the π matrix becomes:

$$\pi = \begin{bmatrix} 0.2+0.3 & 0.5 & 0 \\ 0.5 & 0.2 & 0.3 \\ 0 & 0.3 & 0.2+0.5 \end{bmatrix} = \begin{bmatrix} 0.5 & 0.5 & 0 \\ 0.5 & 0.2 & 0.3 \\ 0 & 0.3 & 0.7 \end{bmatrix} \quad (3)$$

3.2.2 LP Model

From the π matrix, we can see that π_{ik} measures the contribution of A_i to the overall ranking, if A_i is assigned to the k_{th} rank. The larger π_{ij} indicates increased concordance in the assignment of A_i to the k_{th} rank.

Thus the problem is to find A_i for each $k, k = 1, 2, 3, \dots, m$ that maximizes $\sum_{k=1}^m \pi_{ik}$

This is an $m!$ comparison problem. An LP model is suggested for those cases with large m .

Now we define a permutation matrix P as the ($m \times m$) square matrix. Element $P_{ik} = 1$ if A_i is assigned to overall rank k . Otherwise, $P_{ik} = 0$.

The Linear Assignment Method can be written in the following LP format:

$$\begin{aligned} & \text{Max} \sum_{i=1}^m \sum_{k=1}^m \pi_{ik} P_{ik} \\ \text{s.t.} \quad & \sum_{k=1}^m P_{ik} = 1, \quad i = 1, 2, \dots, m \\ & \sum_{i=1}^m P_{ik} = 1 \quad k = 1, 2, \dots, m \\ & P_{ik} \geq 0 \quad \text{for all } i \text{ and } k \end{aligned} \quad (4)$$

Finally, let the optimal permutation matrix, the solution of the above LP problem, be P^* . Optimal ordering can be obtained from $A \times P^*$. To resolve facility layout selection problems with the Linear Assignment Method, we can avoid building detailed qualitative indices and the problems of assigning exact values to attributes. Ranking alternatives of each attribute is easier than defining qualitative indices or deciding exact values.

3.3 The Nemawashi Model

Watabe *et al.* (2002) proposed a Nemawashi model for multi-participant decision-making problems. After discovering that the decision making process in Japanese organizations is different from that in western organizations, they developed this model of Japanese decision-making.

3.3.1 Japanese Decision Making

In American and European organizations, decision-making tends to be relatively individualistic or autocratic. It is often handled by only a few decision makers, even though the decision may concern many participants. In the Japanese style of decision-making, all people related to the decision participate in the decision process. They all influence the decision. Ouchi (cited in Watabe *et al.*) (2002), showed that the number of decision participants is usually four to ten. For important decisions, there may be as many as 60 to 80 participants.

In general, a person or a small group is assigned the role of coordinator. This person works toward gaining consensus among participants by obtaining their opinions, carrying out negotiations, and engaging in persuasion. In Japanese, the process of gaining consensus is called Nemawashi.

After gaining consensus, the coordinator prepares a formal document detailing the proposal and circulates it among participants for consent. This document circulation stage of decision-making is called “ringi.”

This model attempts to improve the disadvantages mentioned above. Thus, the Nemawashi approach can be more profitable.

3.3.2 Description of the Nemawashi Model

Chiou *et al.* (1997) summarized the Nemawashi model and process as in Table 4. The weighting strategy applied here is weight by individual influence (F). The alternative selected is least sum of preference difference weighted by individual influence. This model can be used to select among facility layout alternatives.

When the utility of each layout alternative has been calculated, manager can base on the utility or the opinion of expert to select some candidate alternatives for group negotiation. The decision flow for group negotiation we proposed is illustrated as shown in Figure 2. E is a matrix that shows an evaluation of each candidate alternatives on

each criterion. The element e_{ij} ($i = 1$ to $h, j = 1$ to g) of E is the evaluation of the i th alternative with respect to the j th criterion. C is a matrix that shows each participant's weight for each criterion. The element $c_{j,k}$ ($j = 1$ to $g, k = 1$ to p) of C is an indicator of how important criterion j is to participant k . Moreover, we assume that $\sum_j c_{j,1} = \sum_j c_{j,2} = \dots = \sum_j c_{j,p}$ in order to treat individual differences in a normalized manner. This matrix is constructed by directly ask the participant to evaluate priorities of criteria.

4. A Numerical Example

An IE engineer in company U, a Taiwan electronic manufacturing company, was responsible for the facility layout planning of a new production area. The production line was set for manufacturing (assembly, test, and packing) of LCDTV. Since the LCDTV product is of large size, heavy weight, and has a fragile LCD panel, material flow was emphasized in facility layout planning.

Table 4. Data required for Nemawashi coordinator

Data	Definition	Specification
Alternative evaluation matrix E	The coordinator should propose some alternatives, sets up some attributes for judging alternatives in advance. Then decides the values of every alternative on each attribute after gathering experts and team members' opinions.	i : alternatives, $i = 1, 2, 3, \dots, h$ j : attributes, $j = 1, 2, 3, \dots, g$ e_{ij} : the value of alternative i in attribute $j, e_{ij} \geq 1$.
Individual criteria priority matrix C	The coordinator should decide the weight that every decision maker put on each attribute. The information can be obtained from interviewing with decision makers, or request them to offer it directly.	j : attributes; $j = 1, 2, 3, \dots, g$ k : decision makers, $k = 1, 2, 3, \dots, p$ c_{jk} : the weight that decision maker k put on attribute j , $1 \leq c_{jk} \leq 10$. Assumption: $\sum_j c_{j1} = \sum_j c_{j2} = \dots = \sum_j c_{jp}$
Individual influence vector F	Decision makers are representatives from different departments, and therefore stand for different influence on decision.	k : decision makers, $k = 1, 2, 3, \dots, p$ F_k : the influence of decision maker $k, F_k \geq 1$.
Alternative selection support matrix S , ($S = EC$)	This matrix shows the decision makers' preferences on alternatives, larger figure stands for larger preference.	i : alternatives, $i = 1, 2, 3, \dots, h$ k : decision makers, $k = 1, 2, 3, \dots, p$ S_{ik} : the k decision maker's preference on alternative i .
Consensus matrix $S(A), S(A) = EC(A)$	To every non-consensus alternative (denoted by $A, A = 1, 2, 3, \dots, h$), find out a $C(A)$ that all decision makers prefer alternative A (i.e. $S_{Ak}(A) \geq S_{ik}(A)$).	The proposed linear programming method can be applied to find out a $C(A)$ for every A . Suppose $k \in A$ denotes the decision makers that prefer A , and $k \notin A$ denotes the decision makers that do not prefer A , then the LP model is: $\text{Min } \sum_i \sum_k c_{ik}(A) - c_{jk} $ $s.t. S_{Ak}(A) \geq S_{ik}(A)$ $\sum_j c_{j1}(A) = \sum_j c_{j2}(A) = \dots = \sum_j c_{jp}(A)$ $c_{jk} \notin A(A) \leq 10$ $c_{jk} \notin A(A) \geq 1$ $c_{jk} \in A(A) = c_{jk} \notin A$
Difference of preference matrix $P(A) = C(A) - C$	This matrix shows the efforts to turn current situation into consensus on alternative A .	j : attributes, $j = 1, 2, 3, \dots, g$ k : decision makers, $k = 1, 2, 3, \dots, p$ $p_{jk}(A) = c_{ik}(A) - c_{jk} $

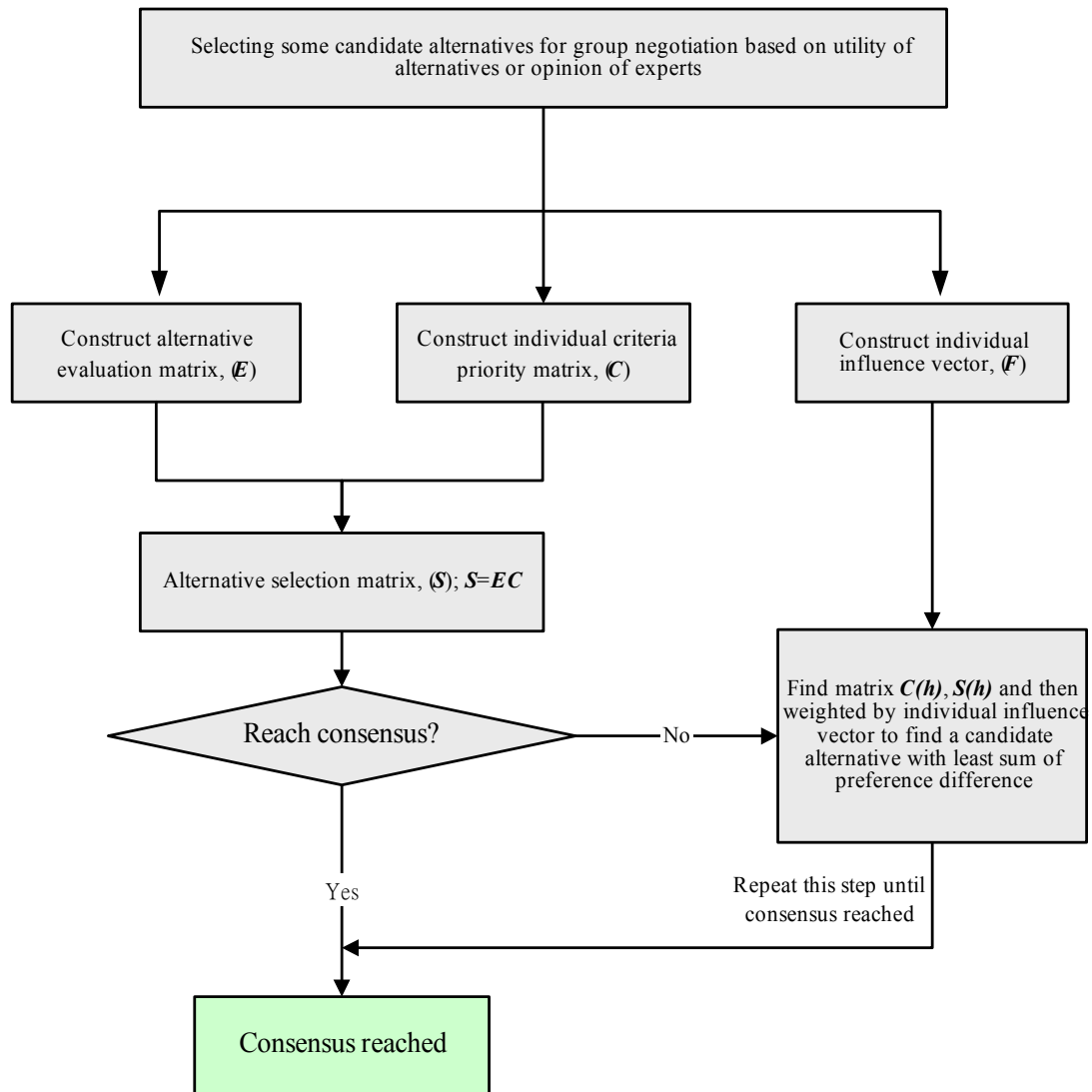


Figure 2. Nemawashi process with proposed model

The IE engineer developed many alternatives, selecting eight possible plans. A, B, C, D, E, F, G, and H. The eight alternatives are illustrated in Figure 3. Characteristics and differences among these eight alternatives are summarized here:

Plan A: material warehouse and rest room are outside production area, located at the right and top side, respectively. The burn-in room is in the middle of the production area. There is an aisle beside the burn-in room to communicate the front and rear production area. As to the conveyor, there is a 30 meters assembly operation conveyor, and an 18 meters test operation conveyor. Plan B: the burn-in room is beside the production area. Plan C: includes a 24 meters loop-flow conveyor. The conveyor is a second-hand conveyor with low purchasing cost is lower. Plan D: there is no aisle beside the burn-in room. Total production area is smaller. Plan E: material warehouse is inside the production area. There is no aisle beside the burn-in room.

Plan F: material warehouse is inside production area burn-in room is beside the production area. Plan G: material warehouse is inside the production area, rest room is on the right side, and there is no aisle beside the burn-in room. Plan H: material warehouse is inside the production area, rest room is on the right side, and burn-in room is beside the production area.

As standing on more specific and technical viewpoints, the IE engineer applied the 18 attributes of Lin and Sharp 1999a (Table 2) and the liner assignment method of Barnade and Blin (1977) to rank these eight alternatives.

Some attributes were abandoned as redundant. The attributes included in this sample were initial cost, annual operation and maintenance cost, clearness, space sufficient and utilization, aisle, distance and volume density, and work related comfort. If the decision maker weights each attribute in sequence as 0.15, 0.15, 0.1, 0.2, 0.1, 0.2 and 0.1, and the ranks of the eight alternatives (plan A-H) are as follows:



Figure 3. Eight facility layout alternatives

1. Initial cost: C, GE, HF, D, A, B
2. Annual operation and maintenance cost: D, HG, EE, ABC
3. Clearness: B, A, HF, C, D, GE
4. Space sufficient and utilization: B, A, C, FH, EG, D
5. Aisle: B, AC, FH, D, EG

6. Distance and volume density: EG, AC, D, FH, B
7. Work-related comfort: H, FCBA, G, ED

For instance, in the attribute of initial cost, the first ranking is Plan C, Plan G and E bear the second ranking, Plan H and F bear the third ranking, Plan D, A, B are the fourth, fifth and sixth ranking respectively.

Table 5. The weighting of attributes and ranking of alternatives

Set with three attribute groups, seven attributes classes and 18

The structured criterion set for plant layout evaluation

Cost 0.3		Flow 0.6			Environment 0.1			
Non-inventory 0.3		Inventory		Space relationship 0.3	Material flow 0.3	Robustness and flexibility	Surrounding	Environment quality 0.1
C	Initial cost:	Raw materials inventory holding cost	B	Clearness 0.1	Aisle 0.1	B	Topography and topology	Human-related safety
GE	Land 0.15		A			AC		
HF	Building		HF		Distance and volume density	FH	Community environment	Worker-related comfort 0.1
D	Production	WIP inventory holding cost	C	Space sufficiency and utilization		D		
A	Machinery		D			E		
B	Material Handling equipment 0.15		GE			G		
				B 0.2	EG 0.2			Property-related security
D	Annual operation and maintenance cost:	Finished goods inventory holding cost	A			AC		
HG			C			D		
EF	Labor Utility Maintenance		EH			FH		
ABC			EG			B		Access for maintenance
	Future salvage value		D					

The weighting of attributes and the ranking of alternatives in each attribute are also illustrated in Table 5.

The π matrix is:

$$\pi = \begin{matrix} & 1_{st} & 2_{nd} & 3_{rd} & 4_{th} & 5_{th} & 6_{th} & 7_{th} & 8_{th} \\ \begin{matrix} \text{Plan A} \\ \text{Plan B} \\ \text{Plan C} \\ \text{Plan D} \\ \text{Plan E} \\ \text{Plan F} \\ \text{Plan G} \\ \text{Plan H} \end{matrix} & \begin{bmatrix} 0 & 0.475 & 0 & 0.05 & 0.15 & 0 & 0 & 0 & 0 \\ 0.4 & 0.025 & 0 & 0.05 & 0.2 & 0.15 & 0 & 0 & 0 \\ 0.15 & 0.175 & 0.2 & 0.15 & 0 & 0 & 0 & 0 & 0 \\ 0.15 & 0 & 0.2 & 0.3 & 0.1 & 0.2 & 0 & 0 & 0 \\ 0.1 & 0.075 & 0.075 & 0.05 & 0.15 & 0.05 & 0 & 0 & 0 \\ 0 & 0.025 & 0.25 & 0.2 & 0 & 0 & 0 & 0 & 0 \\ 0.1 & 0.15 & 0.1 & 0 & 0.15 & 0.05 & 0 & 0 & 0 \\ 0.1 & 0.075 & 0.175 & 0.2 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{matrix} \quad (5)$$

The LP model is:

$$\begin{aligned} & \text{Max.} \quad \sum_{i=1}^8 \sum_{k=1}^8 \pi_{ik} p_{ik} \\ \text{s.t.} \quad & \sum_{k=1}^8 p_{ik} = 1, \quad i = 1, 2, \dots, 8 \\ & \sum_{i=1}^8 p_{ik} = 1 \quad k = 1, 2, \dots, 8 \\ & p_{ik} \geq 0 \quad \text{for all } i \text{ and } k \end{aligned} \quad (6)$$

With the linear programming software LINGO, the solution of this LP model is:

$$P^* = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (7)$$

This shows the optimal alternative ranking is:

$A \times P^* = (\text{Plan B, Plan A, Plan F, Plan H, Plan E, Plan D, Plan C, Plan G})$

Considering the similarity between alternatives, the IE engineer selected Plans B, A, F, and H as candidates for group decision.

In Company U, the managers concerned in this LCDTV facility layout project participated in the selection decision. They are the managers of the Manufacturing Division (MD), Production Department (PD), Business Division (BD), IE Department (IE), and Quality Assurance Division (QA).

Since top managers make their decisions with more strategic concerns, the IE engineer applied Muther's (1973) 20 attributes to the attributes used in company U. The attributes are capable of distinguishing among the four candidate plans were: flexibility of layout, quality of product or material, flow or movement effectiveness, space utilization, appearance, promotional value, public or community relations, and working conditions and employee satisfaction.

After discussing among the IE partners, the IE engineer created plan evaluation matrix E

$$\text{(set } \sum_{j=1}^4 e_{ij} = 20, \quad i = 1, 2, \dots, 6 \quad \text{and } 1 \leq e_{ij} \leq 10 \text{):}$$

$$E = \begin{matrix} & \begin{matrix} \text{Flexibility} & \text{Quality} & \text{Flow} & \text{Space} & \text{Appearance} & \text{Employee} \end{matrix} \\ \begin{matrix} \text{Plan B} \\ \text{Plan A} \\ \text{Plan F} \\ \text{Plan H} \end{matrix} & \begin{bmatrix} 9 & 5 & 3 & 10 & 4 & 4 \\ 3 & 9 & 9 & 6 & 10 & 4 \\ 4 & 3 & 4 & 2 & 3 & 3 \\ 4 & 3 & 4 & 2 & 3 & 9 \end{bmatrix} \end{matrix} \quad (8)$$

The individual criteria priority matrix C was also created after interviewing the top managers

$$\text{(set } \sum_{k=1}^6 c_{jk} = 20, \quad j = 1, 2, \dots, 5 \quad \text{and } 1 \leq c_{jk} \leq 10 \text{):}$$

$$C = \begin{matrix} & \text{MD} & \text{PD} & \text{BD} & \text{IE} & \text{QA} \\ \text{Flexibility} & \begin{bmatrix} 5 & 1 & 1 & 6 & 2 \end{bmatrix} \\ \text{Quality} & \begin{bmatrix} 4 & 4 & 6 & 2 & 10 \end{bmatrix} \\ \text{Flow} & \begin{bmatrix} 2 & 2 & 1 & 4 & 2 \end{bmatrix} \\ \text{Space} & \begin{bmatrix} 5 & 7 & 5 & 4 & 2 \end{bmatrix} \\ \text{Appearance} & \begin{bmatrix} 2 & 2 & 6 & 2 & 2 \end{bmatrix} \\ \text{Employee} & \begin{bmatrix} 2 & 4 & 1 & 2 & 2 \end{bmatrix} \end{matrix} \quad (9)$$

This produces the selection support matrix S:

$$S = \begin{matrix} & \text{MD} & \text{PD} & \text{BD} & \text{IE} & \text{QA} \\ \text{Plan B} & \begin{bmatrix} 137 & 129 & 120 & 132 & 110 \end{bmatrix} \\ \text{Plan A} & \begin{bmatrix} 127 & 135 & 160 & 124 & 154 \end{bmatrix} \\ \text{Plan F} & \begin{bmatrix} 62 & 56 & 57 & 66 & 62 \end{bmatrix} \\ \text{Plan H} & \begin{bmatrix} 74 & 80 & 63 & 78 & 74 \end{bmatrix} \end{matrix} \quad (10)$$

Based on the S matrix, Plan F and Plan H could be eliminated: no participant preferred these two plans. Since two participants preferred Plan B and three participants preferred Plan A, we needed to develop a new C(B) and C(A) respectively for distinguishing between Plan A and B.

To find C(B) and C(A) closest to the original C, we needed to solve the LP model:

$$\begin{aligned} & \text{Min} \quad \sum_{k=1}^5 \sum_{j=1}^6 |C_{jk}(x) - C_{jk}| \\ \text{s.t.} \quad & S_{jk}(x) \geq S_{ik}(x) \\ & \sum_{j=1}^6 C_{j1}(x) = \sum_{j=1}^6 C_{j2}(x) = \sum_{j=1}^6 C_{j3}(x) = \sum_{j=1}^6 C_{j4}(x) = \sum_{j=1}^6 C_{j5}(x) \\ & C_{j,k \notin x}(x) \leq 10 \\ & C_{j,k \notin x}(x) \geq 1 \\ & C_{j,k \in x}(x) = C_{j,k \in x} \end{aligned} \quad (11)$$

Where members preferring Plan X are denoted $k \in x$

With the software LINGO, solving the model produced C(A) and C(B)

$$\begin{matrix} & \text{MD} & \text{PD} & \text{BD} & \text{IE} & \text{QA} \\ \text{Flexibility} & \begin{bmatrix} 4.17 & 1 & 1 & 5.33 & 2 \end{bmatrix} \\ \text{Quality} & \begin{bmatrix} 4.00 & 4 & 6 & 2.00 & 10 \end{bmatrix} \\ \text{Flow} & \begin{bmatrix} 2.16 & 2 & 1 & 4.29 & 2 \end{bmatrix} \\ \text{Space} & \begin{bmatrix} 5.00 & 7 & 5 & 4.00 & 2 \end{bmatrix} \\ \text{Appearance} & \begin{bmatrix} 2.67 & 2 & 6 & 2.37 & 2 \end{bmatrix} \\ \text{Employee} & \begin{bmatrix} 2.00 & 4 & 1 & 2.00 & 2 \end{bmatrix} \\ & \text{MD} & \text{PD} & \text{BD} & \text{IE} & \text{QA} \\ \text{Flexibility} & \begin{bmatrix} 5 & 1.03 & 4.62 & 6 & 6.03 \end{bmatrix} \\ \text{Quality} & \begin{bmatrix} 4 & 3.98 & 6.00 & 2 & 8.04 \end{bmatrix} \\ \text{Flow} & \begin{bmatrix} 2 & 1.90 & 1.00 & 4 & 1.00 \end{bmatrix} \\ \text{Space} & \begin{bmatrix} 5 & 7.59 & 4.66 & 4 & 2.00 \end{bmatrix} \\ \text{Appearance} & \begin{bmatrix} 2 & 1.52 & 2.72 & 2 & 1.00 \end{bmatrix} \\ \text{Employee} & \begin{bmatrix} 2 & 3.98 & 1.00 & 2 & 1.94 \end{bmatrix} \end{matrix} \quad (12)$$

Since the selection strategy of least sum of preference difference weighted by individual influence was applied, we need to compare C(A) and C(B) to the original C. This result in the difference of preference P(A)

and P(B):

$$\begin{matrix} & \text{MD} & \text{PD} & \text{BD} & \text{IE} & \text{QA} \\ \text{Flexibility} & \begin{bmatrix} 0.83 & 0 & 0 & 0.67 & 0 \end{bmatrix} \\ \text{Quality} & \begin{bmatrix} 0.00 & 0 & 0 & 0.00 & 0 \end{bmatrix} \\ \text{Flow} & \begin{bmatrix} 0.16 & 0 & 0 & 0.29 & 0 \end{bmatrix} \\ \text{Space} & \begin{bmatrix} 0.00 & 0 & 0 & 0.00 & 0 \end{bmatrix} \\ \text{Appearance} & \begin{bmatrix} 0.67 & 0 & 0 & 0.37 & 0 \end{bmatrix} \\ \text{Employee} & \begin{bmatrix} 0.00 & 0 & 0 & 0.00 & 0 \end{bmatrix} \\ & \text{MD} & \text{PD} & \text{BD} & \text{IE} & \text{QA} \\ \text{Flexibility} & \begin{bmatrix} 0 & 0.03 & 4 & 0 & 4 \end{bmatrix} \\ \text{Quality} & \begin{bmatrix} 0 & 0.02 & 0 & 0 & 2 \end{bmatrix} \\ \text{Flow} & \begin{bmatrix} 0 & 0.10 & 0 & 0 & 1 \end{bmatrix} \\ \text{Space} & \begin{bmatrix} 0 & 0.59 & 0 & 0 & 0 \end{bmatrix} \\ \text{Appearance} & \begin{bmatrix} 0 & 0.48 & 3 & 0 & 1 \end{bmatrix} \\ \text{Employee} & \begin{bmatrix} 0 & 0.02 & 0 & 0 & 0 \end{bmatrix} \end{matrix} \quad (13)$$

Therefore, the sum of preferences difference for U(A) and U(B) were:

$$U(A) = [1.67 \quad 0 \quad 0 \quad 1.33 \quad 0] \quad (14)$$

$$U(B) = [0 \quad 1.22 \quad 7 \quad 0 \quad 8] \quad (15)$$

Suppose we get the individual influence vector F was set as (set $\sum_{i=1}^5 f_i = 20$):

$$F = \begin{matrix} \begin{bmatrix} 7 \\ 5 \\ 2 \\ 4 \\ 2 \end{bmatrix} & \begin{matrix} \text{MD} \\ \text{PD} \\ \text{BD} \\ \text{IE} \\ \text{QA} \end{matrix} \end{matrix} \quad (16)$$

Use of vector F to weight U(A) and U(B) yielded:

$$U^f(A) = [11.67 \quad 0 \quad 0 \quad 5.33 \quad 0] \quad (17)$$

$$U^f(B) = [0 \quad 6.11 \quad 14.48 \quad 0 \quad 16] \quad (18)$$

The sum of $U^f(A)$ and $U^f(B)$ was:

$$\sum U^f(A) = 17.00 \quad (19)$$

$$\sum U^f(B) = 36.68 \quad (20)$$

Following to the rule $\text{Min}(\sum U^f)$, the IE engineer selected Plan A as the target plan. The next task was to negotiate or persuade all members to accept Plan A as the final decision.

5. CONCLUSIONS

As facility layout problems are usually treated as design problems, few studies focus on the problem of facility layout selection. When facility layout modifications are frequent, the problem is not simply a design problem. Any perfect facility layout design can lose its adequacy after frequent modifications. We found that companies in

EMS industry suffered frequent and costly facility layout modifications. Their main problem was focusing on selecting a suitable layout among many possible alternatives. As a result, the problem became a problem of selection.

The actual decision making situation of facility layouts in this scenario was:

- (1) Design several alternatives in a short time. New layouts did not need to be perfect, but had to be fast and flexible.
- (2) Decide among these alternatives.
- (3) Execute the layout modifications as soon as possible.

Under these conditions, it is important to make good decisions of facility layouts. The actual decision making of facility layout selections is always subjective. After facility layout alternatives are developed, the decisions are made according to manager experience or preference. As the facility layout modifications become frequent and costly, this decision-making problem becomes increasingly important.

To make the selection of facility layout alternatives more objective and effective, we proposed a decision support model. With this model, alternatives are compared according to specific numerical values making the decision-making more objective. The decision-making process follows systematic steps of setting attributes, deciding the quantitative indices, and applying ranking methods. This decision model considered a group decision scenario and proposed decision-making by consensus, achieving the goals of timesaving and overall satisfaction. Finally, this model will show its value once it is frequently used in the process of selecting facility layout alternatives.

We proposed a support model for selecting among facility layout alternatives in an objective and systematic way. This model can be a useful reference in further research on facility layout selection problems.

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