A Decision Support Model for Selecting Facility Layout Alternatives

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A Thesis
Submitted to the Department of Industrial Engineering and
Enterprise Information at Tunghai University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in
Industrial Engineering and Enterprise Information

June 2004
Taichung, Taiwan, Republic of China

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ABSTRACT

Usually, facility layout problems are treated as design problems, not enough research was proposed about the facility layout selection problems. Due to the lack of a systematic and objective tool to compare all the alternatives, the decision-making is mainly dominated by the experiences and preferences of top managers. In order to increase the objectivity and effectiveness of decision-making in facility layout selections, a decision support model is quite necessary.

In public literature review, we investigate some sets of attributes that are crucial to layout selections, the quantitative indices for attributes and the methods applied to rank alternatives. Facility layout designs need to satisfy various objectives in an organization, which results in difficulty in making selection decisions. For a request of facility layout design, there could be plenty of alternatives developed. In such a situation, enormous alternatives and various attributes, as well as assigning qualitative values to each attributes for comparing all alternative, could form a complicate decision problem.

In practical decision-making environment of facility layout selections, two scenarios are often presented. First scenario contains single decision maker. The layout designer screens potential alternatives out of enormous designs for further decision. To treat facility layout selection problems as a Multiple Attributes Decision Making (MADM) problem, we apply Linear Assignment Method to rank all the alternatives, and pick up alternatives with leading position in the ranking as potential candidates. The second scenario is the group decision situation. Selected candidates are offered to a few decision makers, usually top managers, for final selection. We apply the Nemawashi model, a Japanese group decision process, to simulate the group decision-making procedure, and help to achieve an agreement effectively.

We notice that Electronics Manufacturing Services (EMS) industry faces the decision-making situation with frequently and costly facility layout modifications, and our models can be helpful here. A sample in an EMS company is utilized to illustrate the decision process of our model.

There are some characteristics in the model we proposed. The Linear Assignment Method we applied in the single decision maker scenario only requires the decision maker to input the ranking of alternatives with respect to every attribute only. This simplifies the goal of judging alternatives in every attribute, and still achieves the purpose of comparing all alternatives objectively. The group decision application on facility layout selections in this research considers the scenario of multiparticipant decision makers, which we believe that is more close to real decision making situations in enterprises.

Key words: Facility Layout, MADM, Group Decision, Linear Assignment Method, Nemawashi, EMS

設施佈置方案評選之決策支援模式

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摘要

設施規劃問題，通常被視為是設計問題，較少有文獻將其視為選擇問題加以探討。由於欠缺客觀而有系統的工具來比較各個方案，因此設施規劃方案的決策，一般是取決於高層經理人的經驗及偏好。為了提昇此項決策的客觀性及有效性，必須要有一個可供參考的決策支援模式。

經文獻探討，本研究整理出幾組評選設施規劃方案的因子、各項因子的量化指標及方案的排序方法。由於設施規劃的設計要滿足許多組織上的目標，因此在評選設施規劃方案時，需要考量的評估因子也就相當多了。在這樣多方案且多決策因子的情況下，量化各項決策因子並藉此做出決策就顯得複雜與困難了。

真實的設施規劃決策環境裡，包含兩種情境。一是單一決策者的情境，設施規劃案的設計者，在設計的眾多方案中，選擇出較佳的方案。在單人決策的情境中，本研究將設施規劃方案選擇的問題視為是多目標決策的問題，並應用線性指派方法以評斷各方案的優劣，評選出較佳的方案以進行更進一步的評選。另一種情境，是群體決策的情況。初步挑選過後的方案，提供給一群決策者，以進行最後評選。在這個情境中，本研究使用日式磋商過程的模式，以處理設施規劃方案的決策過程，並提供有效達到共識決策的指引。

本研究也發現電子代工產業常面臨高頻率及高成本的設施佈置變更情況，因此本研究所提的決策支援模式，將可在這種情況下有所幫助。本研究使用一個電子代工廠的設施規劃案例，以說明所提出的決策支援模式。

此決策支援模式有幾項特點。我們在單人決策情境中所使用的線性指派方法，只需要決策者在各項因子中決定出各方案的順序，卻依然可以達到評斷方案良窳的結果。且此決策支援模式探討設施規劃評選問題的群體決策情境，將更貼近企業做設施規劃評選決策的實際情況。

關鍵字詞： 設施佈置，多目標決策，群體決策，線性指派方法，日式磋商過程，電子代工產業

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1.1 Facility Layouts

1.1.1 The Definition of Facility Layouts

We can get the concept of facility layouts from some definitions. Sthahl's study (as cited in Alberto and Williamson [1]) regards facility layouts as the arrangement of work space which, in general terms smoothes the way to access facilities that have strong interaction. Its aims are similar regardless of whether the organizations are services or manufacturing. Facilities are of crucial importance to organizations, usually, they represent the largest and most expensive assets of the organizations. This definition gives a macroscopic view at facility layouts. It reveals that facility layout planning is a work to arrange closely related facilities together, and acts similar no matter in manufacturing or service providing industry. Moreover, the work is so important for it stands for lots of asset inputs in every company. Another definition from Evan [4] gives us a more specific picture about facility layout on its functions. In Evans' opinion, facility layouts refer to the specific arrangement of physical facilities. It affects material flow, handling and maintenance costs, equipment utilization, productivity, production flexibility, management effectiveness, and even employee morale. With this definition, we catch the great effect of facility layouts on arranging facilities. Two more definitions are from Reid and Sanders [13], and Stevenson [15]. Reid and Sanders proposed that facility layout planning is deciding on the best physical arrangement of all resources that consume space within a facility. These resources might include a desk, a work center, a cabinet, a person, an entire office, or even a department. Stevenson pointed out that facility layouts refer to 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 various personnel, equipments or departments, and the arrangement has great influences on activities in this organization.

1.1.2 Basic Facility Layout Patterns

For further understanding of facility layout, we should introduce the types and characteristics of facility layouts. Evans proposed four major facility layout patterns: product layout, process layout, group layout and fixed position layout, depicted in the following:

1. Product Layout

The product layout is basically arranged for producing products with high quantity similar production processes. Generally speaking, continuous-flow, mass-production, and batch-processing production process are usually physically organized by product layout. By ordinary, there is a key characteristic in product layout: equipment arrangement is based on the sequence of operations performed in production, and products move in a continuous path from one department to the next. Thus, we can easily observe that materials are inputted one by one into production, and so do the finished goods output.

Compared with other facility layout patterns, product layout possesses some advantages. Since this kind of facility layout provides a smooth and logical flow of production, it is easier to use specialized handling equipment. In addition, small work-in-process inventory could be stocked in production areas because of the flow manufacturing procedure. Moreover, short-unit production time, low material handling, low labor skill requirements, and simple planning and production-control system are all noticeable merits of product layout.

However, product layouts own several disadvantages also. First, a breakdown in one machine can cause an entire production line to shutdown because the flow production procedure is interrupted. Next, a change in product design or the introduction of new products may require major changes in the existing layout, and the layout change is often costly. Further, the capacity of the production line is determined by the bottleneck work center, and therefore line balance is a critical issue here. Finally, because of the high level of division of labor often required, product layouts usually provide little job satisfaction, which results in monotony.

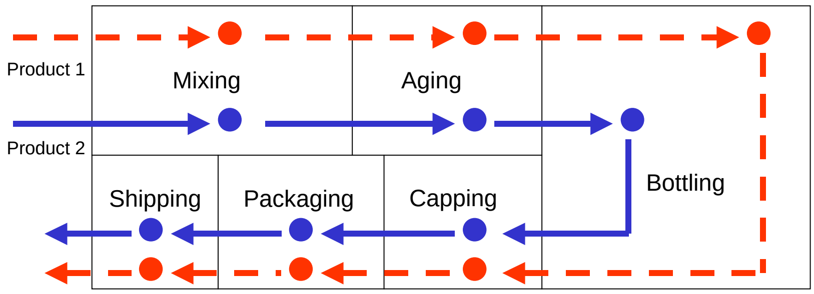


Figure 1.1 An illustration of product layout

Source: [4]

2. Process Layout

The process layout consists of a functional grouping of machines or activities that do similar work. Therefore, the manufacturing process, or procedure, of each product decides the material flow in process layout. An example of process layout is job shops. Job shops uses process layout to provide flexibility in the products that can be made and the utilization of equipment and labor.

Contrasted to product layout, process layout has two major advantages. In general, process layout requires a low investment in equipment. The lower investment is mainly because the machines in process layout are always with common use, or all-purpose use functions. And these common machines are always cheaper than those special purpose machines used in product layouts. The other advantage is that job satisfaction is increased, for job diversity comes along with process layout always.

As to the shortcomings, some items are proposed. Since products must be moved between departments frequently, the material handling and transportation costs are high. Next, we realize that each product has its flow direction in process layout, as products go variously, the production planning and control systems turn out to be complicated. Additionally, process layout often causes longer total production time, since material handling between departments is increased. Furthermore, process layout suffers higher work-in-process inventory, that is because jobs from several departments may need to share a particular group of machines, and this creates material stocks before bottleneck departments. Finally, in order to deal with various work orders, operators should be with higher skills.

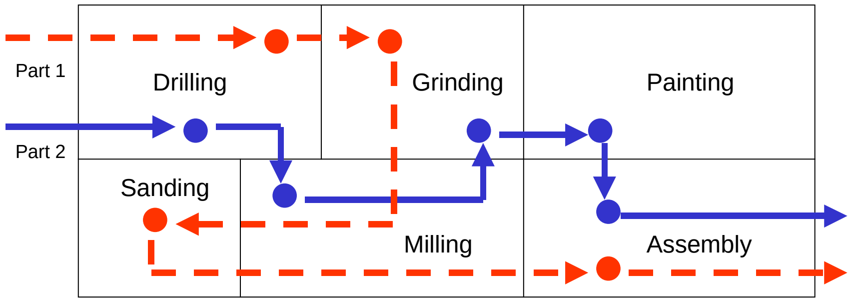


Figure 1.2 An illustration of process layout

Source: [4]

3. Group Layout

The idea of group layout, or cellular manufacturing, is the compromise between product layouts and process layouts. It classifies parts into families at first, and then arranges the layouts or machines according to the process of each parts family. Thus, machines are grouped by the requirements of parts families, but not functional characteristics. To illustrate the concept of group technology, suppose two parts families, A and B, are produced in process layout currently in Figure 1.3. The concept of group layout is to make Milling and Drilling from public use of Family A and B to be private use separately. The modification is shown in Figure 1.4.

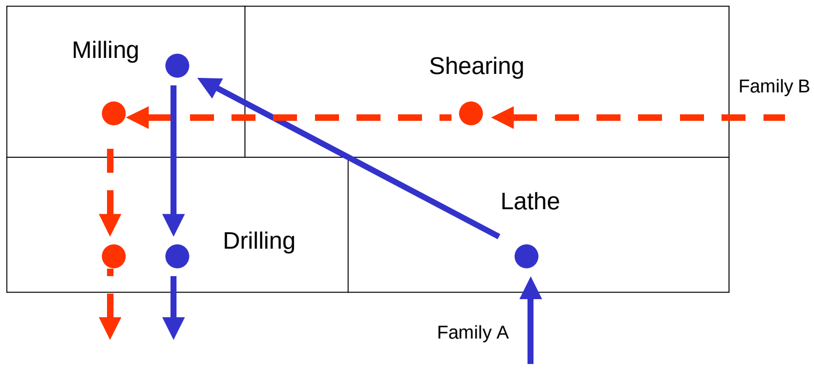


Figure 1.3 A work flow illustration of parts families A and B in process layout

Source: [4]

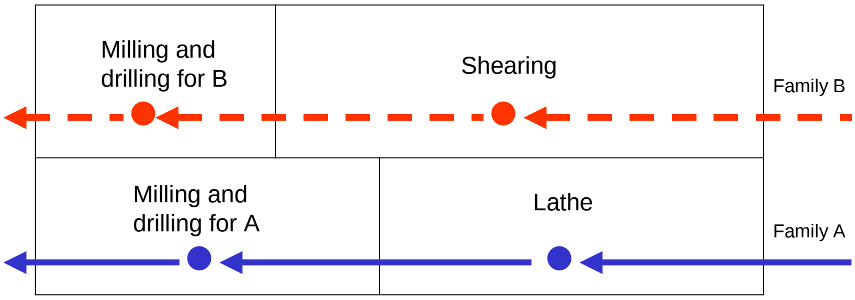


Figure 1.4 A work flow illustration of parts families A and B in group layout

Source: [4]

Group layouts contribute a lot on reducing material handling cost that occurred in process layouts. It helps works be able to concentrate on production rather than on moving parts between machines. And one more remarkable benefit is that because part families own similar features, machine setup is much more easier than that in process layout. On the other hand, group layouts keep more flexible than product layouts. It is more capable of serving various products.

But some drawbacks occurred. In order to classify parts or products into families, we need group technology to achieve it. While group technology requires a systematic analysis on a company's production process, and this work is time-consuming.

4. Fixed Position Layout

In some cases, the products we produced are large or heavy, ships, airplanes, for instance. So instead of moving materials or work-in-process, we prefer to move machines and workers in production. Usually, once the products are costly to do the transportation, fixed position layout could be the best choice for production.

Evans also summarized the relative features of product, process and group layout shown in Table 1.1 for selecting suitable pattern, trade-off between flexibility and productivity is the key evaluation point.

Table 1.1 Comparison of basic layout patterns

Factor	Process Layout	Product Layout	Group Layout
Amount of flexibility	High	Low	Moderate
Automation potential	Low	High	Moderate
Type of equipment	General-purpose	Highly specialized	Some specialization
Production volume	Low	High	Moderate
Equipment utilization	Low	High	Moderate
Setup costs and reguirement	Low	High	Moderate

Source: [4]

Similarly, Reid and Sanders compared the two extreme layout patterns, process layout and product layout, by some characteristics in Table 1.2.

Table 1.2 Characteristics of process and product layout

Process Layouts	Product Layout
Able to produce a large number of different products	Able to produce a small number of products efficiently
Resources used are general purpose	Resources used are specialized
Facilities are more labor intensive	Facilities are more capital intensive
Greater flexibility relative to the market	Low flexibility relative to the market
Slower processing rates	Processing rates are faster
High material handling costs	Low material handling costs
Higher space requirements	Low space requirements

Source: [12]

We usually find that a company may apply several facility layout patterns in its organization, that's because different patterns satisfy different product production requirements. The pattern that brings the best benefit is certainly the right one should be applied.

1.1.3 Facility Layout Modifications

Since the facility layouts in a facility can significantly affect the productivity of a business, and a proper layout planning can be critical in building good working relationships, increasing the flow of information, and improving communication [12], we surely like to have the best facility layout at any time. Therefore, we make efforts on designing a good facility layout in the very beginning, and expect the well-designed facility layout contributes to highly productive organizations all the time. But unfortunately, facility layouts need modifications in some cases.

Decisions about the arrangement of resources in a business are not made only when a new facility is being designed, they are made any time there is a change in the arrangement of resources, such as a new worker being added, a machine being moved, or a change in procedure being implemented. Also, layout planning is performed any time there is an expansion in the facility or a space reduction [12]. So, facility layout planning is a work appears at any moment in an organization's running.

There are lots of operation problems in any organization, some can be solved easily, and some are not. But all these problems give chances for an organization to improve. Shafer and Meredith [13] mentioned some operation problems might indicate the need for facility layout modifications, such as:

1. Congestion.
2. Poor utilization of space.
3. Excessive amounts of materials in the workflow.
4. Bottlenecks occurring in one location simultaneously with idleness in another.
5. Skilled workers doing excess unskilled work.
6. Long operation cycles and delays in delivery.

7. Anxiety and strain among workers.

8. Difficulty in maintaining operational control of work and staff.

We can realize that most facility layouts are originally designed efficiently, but as the organization grows and changes to accommodate a changing environment, the facility layout becomes less efficient, and until eventually a facility layout modification is necessary.

The facility layout modifications act over and over again as long as the organization is running, and each modification action implies an effort to achieve the best layout design.

1.2 Facility Layout Problems in EMS Industry

1.2.1 EMS Industry

The EMS (Electronics Manufacturing Services) industry is providing OEMs (Original Equipment Manufacturers) all kinds of electronic products and customized products with lower cost and 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. EMS companies test the product, prepare it for manufacturing and then take it to full production. EMS companies box the product, ship it and even install it. Once in use, EMS companies provide end-customer service and technical support. And if repairs are required, EMS companies make the fix.

In order to achieve customer satisfaction, EMS companies need to be good at doing some jobs, such as global logistics, mass production, cost control, ability to design and flexibility, and these emphases form the characteristics of all the EMS companies.

More and more leading OEMs are relying on EMS providers to assemble their products. The major drivers pushing OEMs to outsource include continuous market pressures to shorten time-to-market, enhance asset utilization and master the complexity of process technologies. In essence, outsourcing enables OEMs to focus on their core competencies, which include research and development, sales and marketing. The main reasons of outsourcing from OEMs are summarized as follows:

1. Time to market: in the intensely competitive electronics industry, companies have only a small window of opportunity in which to deliver products to market. The earliest entrants to the market can often reap significant financial rewards as well as the dominant market share. Faced with shortened product life cycles, electronics OEMs are forced to reduce their time-to-market to remain competitive. By working with EMS providers, the OEM can achieve faster time-to-market.

2. Economics: OEMs who choose to outsource realize significant financial benefits when partnering with EMS providers. EMS providers focus on offering low manufacturing costs and savings are passed on to OEMs. In addition, the risks of frequent design changes, shorter product life cycles, component price fluctuations, component shortages and increased product complexities are significantly reduced.

3. Advanced technology: as electronics products become more technologically advanced, manufacturing processes become more sophisticated. Thus, OEMs face greater difficulty in maintaining the technological expertise needed to remain competitive with each successive product generation. By partnering with EMS providers, OEMs can gain access to the latest equipment, process knowledge and manufacturing expertise without making substantial capital investments.

4. Enhanced asset utilization: for various kinds of products, OEMs need to keep huge investments in equipments and related technicians. With outsourcing, OEMs can have a better control over assets, and avoid the risk of equipments and manpower investment.

To be brief, when OEMs are developing a product, EMS providers could bring OEMs more profit.

1.2.2 Frequent and Costly Facility Layout Modifications in EMS Companies

For the sake of keeping long-term and stable partnership with OEMs, EMS companies undertake a number of burdens unfavorably. Some are related to facility layouts.

Ordinarily, an EMS company offers manufacture service to several OEMs simultaneously. But for product secrets, quality assurance and other management concerns, almost all the OEMs request private production areas. Satisfying leading OEMs with private production areas or production departments makes the whole facility layout in a company separated into parts. Facility layout modifications consequently occur for the cooperation growth or decline between the EMS companies and OEMs.

In addition to the cooperation situations, the business status of each OEM results in EMS's facility layout modifications also. The business status of each OEM directly affects the orders to its EMS partners, and that means the required production capacities to EMS companies are dynamic. Because the production areas and equipments are allocated to certain OEMs already, the capacity variations from any OEM therefore cause the facility layout modifications. Either to enlarge the production areas and add equipments, or allocate the space and equipments to another OEM, both come up the facility layout modifications.

Similar situation arises when new products are introduced into any OEM's production area. New products introductions may not only create extra capacity requirements, even some special equipment demands may occurred. These special equipments perhaps need particular infrastructures, such as water drain, constant temperature or damp…so on, add these equipments into production lines, facility layout modifications are needed still.

Company U, a worldwide EMS firm with headquarters in Taiwan, is experiencing costly and frequently facility layout modifications. The facility layout modification evidences of two manufacturing sites in Taiwan are summarized in Table 1.3, 1.4 and 1.5. This summary gives us a picture about the real condition of facility layout modifications, and highlights the essentiality to face this problem seriously.

Table 1.3 A facility layout modifications summary of company U in 2001

Facility layout modification evidences in 2001

Item	Month	Specification	Layout type	Cost (approx.) NTD.
1-1	2	Production line movement(Plant 1 to Plant 2, PD1 print 100K clean room)	Production area	1.6 million
1-2	3	Production department movement (Plant 2 to Plant NK, PD2)	Production area, office	NA
1-3	4	Production department movement (Plant 2 to Plant NK, PD5)	Production area, office	NA
1-4	4	Office re-layout (Plant 2, 5F)	Office	NA
1-5	4	Partition building for office	Office	55 thousand
1-6	4	EQ department office	Office	NA
1-7	5	Production line switch (Plant 2 to Plant NK, PD2)	Production area	1 million
1-8	6	Dock building (second) for material receving	Production area	450 thousand
1-9	6	Production line movement(Plant 1 to Plant 2, PD1 PWR)	Production area	515 thousand
1-10	8	Office layout for top managers	Office	300 thousand
1-11	8	Re-layout for Dell requisition (PD2)	Production area	NA
1-12	8	Re-layout for ECU Expand (PD1)	Production area	104 thousand
1-13	8	Production line movement(Plant 1 to Plant 2, PD1 ECU)	Production area	600 thousand
1-14	9	Production line movement(Plant 1 to Plant 2, PD1 HIC assembly and testing)	Production area	610 thousand
1-15	9	Production line movement(Plant 1 to Plant 2, PD1 4F 10K class clean room)	Production area	4.7 million
1-16	11	CBG BD/PMC office and warehouse movement(Plant 1 to Plant 2)	Production area, office	840 thousand
1-17	11	Production line movement(Plant 1 to Plant 2, PD1 REG)	Production area	3.4 million

Remark: NA means the data is Not Available.

Table 1.4 A facility layout modifications summary of company U in 2002

Facility layout modification evidences in 2002

Item	Month	Specification	Layout type	Cost (approx.) NTD.
2-1	1	Re-layout for adding space utilization (PD4)	Production area	350 thousand
2-2	1	Production line Re-layout(PD2)	Production area	100 thousand
2-3	1	CBG RD/QA office/lab movement(Plant 1 to Plant 2)	Office, Lab	590 thousand
2-4	2	New production line setup (PD1 EPS)	Production area	120 thousand
2-5	2	CBG RD office movement(Plant 1 to Plant 2)	Office	215 thousand
2-6	3	RD departments movement (Plant NK to Plant 1)	Office, Lab	1.7 million
2-7	3	Production line movement(Plant 1 to Plant 2, PD1 ECU GenI)	Production area	270 thousand
2-8	4	SMT line switch (From PD4 to PD5)	Production area	60 thousand
2-9	5	Re-layout for adding one SMT line (PD2)	Production area	180 thousand
2-10	5	Re-layout for OA office (RD, Plant1)	office	NA
2-11	5	Re-layout for New Prodction MSB (PD1)	Production area	25 thousand
2-12	6	MP&VQA&QC department relayout(3F to 4F)	Office	1 million
2-13	7	PD5 relayout(Agere/Proxim)	Production area	500 thousand
2-14	8	Re-layout for COM2 RD office	office	NA
2-15	9	Layout plan for RD office (Tai-Chung)	office	NA
2-16	9	Re-layout for change two SMT line (PD2)	Production area	800 thousand
2-17	9	Production line movement(Plant 1 to Plant 2, RD1 clean Room and PD1 Chip-R/RNW)	Production area	1.5 million
2-18	10	Re-layout for OSC new process(PD1)	Production area	130 thousand
2-19	10	Re-layout for remove one SMT line(PD2)	Production area	400 thousand
2-20	10	Re-layout for capacity reduction (PD3)	Production area, office	200 thousand
2-21	11	New production line setup (PD1 MCM)	Production area	430 thousand

Remark: NA means the data is Not Available.

Table 1.5 A facility layout modifications 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 producion BTM at NK Plant(PD1)	Production area	200 thousand
3-6	3	New producion EMS at NK Plant	Production area	85 thousand
3-7	3	New production area(PD7) in NK Plant 5F	Production area, office	1.2 mllion
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 prodution 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.

1.3 Motivation and Objectives

1.3.1 Motivation

The frequent layout modification evidences in EMS industry were unavoidably observed in practice. The real facility layout planning in this scenario is as follows: First, design several alternatives in a short time, the new layout designs don't need to be perfect, but must be fast and flexible. Second, make a decision within these alternatives. Third, execute the layout modifications as soon as possible.

Obviously, under such a scenario, a good tool for evaluating layout alternatives while making decisions turns out to be critical to layout modification costs. Good decisions may bring fewer layout modification chances, or decrease the expense of each layout modification event.

Based on the attempt of decreasing facility layout costs caused in this scenario, we raise the motivation to develop a decision support model for selecting facility layout alternatives. This model can be applied on general facility layout alternative selection problems, not limited to EMS industry.

1.3.2 Objectives

Usually, due to the lack of a systematic and objective tool, the decision making for selecting facility layout alternatives is mainly dominated by the experiences and preferences of top managers. Under such a situation, the decision making therefore is subjective and unstructured. In addition, since facility layouts affect so many departments and personnel in an organization, the decisions are always made by a group of decision makers, not a single decision maker. By the way, the decision making certainly takes lots of time once there are multiple decision makers.

As a result, we try to construct a decision support model for providing necessary information for decision makers. With the model, decision makers may have qualitative data as references for making decisions.

After examining above shortcomings in current decision making process, we set some goals for developing this decision support model:

1. Objective decision making: the model enabling the decision should be made according to objective data or figures.

2. Systematic decision making process: the model should offer a structured process, that is, to decide attributes, compare alternatives in each attributes, and then 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 among multiple decision makers.

In order to construct a model satisfied the four goals mentioned above, we reviewed the attributes and qualitative indices for selecting facility layout alternatives. Next, we reviewed the alternative ranking methods in decision making category. After considering the characteristics of facility layout selection problem, we construct a decision support model for selecting facility layout alternatives. The model discusses both single decision maker and multiple decision makers scenarios.

With the four goals, this supporting model is therefore expected to achieve our objectives for improving the quality of decisions for selecting layout alternatives.

1.4 Research Contributions

In the study, we deal with the facility layout selection problems. After literature review, we find that few researches discuss about the problems of facility layout selections. Decision makings for selecting facility layout alternatives therefore were treated subjectively, uncertainly and carelessly because of lacking essential decision information or tools. The model we proposed offers assistances in decision information collection and analysis.

In addition, we treat the facility layout selection problem as a MADM problem, and thus bring us various methods or models for solving this problem. The Linear Assignment Method we applied in this paper can avoid the usual difficulty in judging exact quantitative figures of every alternative in each attribute, only the ranking information of alternatives is required, and no complex calculation efforts. These advantages greatly facilitate the application difficulty of this model.

Moreover, facility layout problems affect lots of departments and staffs in an organization enormously, so the decision makers are usually multiple, or even a group. The model we proposed discusses about the situation of group decision making, which we believe that are closer to the real decision making situations in enterprises, and facilitate the decision making in groups.

Finally, this decision support model is a mathematical model, which means easy to be computerized and transferred into programs. Thus, a user-friendly decision support system is expectable.

In short, the contributions of this study are as follows:

1. We review and discover the facility layout selection problem, which is not a design problem as classical view on facility layout problem.
2. We apply an adequate mathematical method, Linear Assignment Method, to solve the facility selection problem.
3. We apply a group decision method, Nemawashi, to solve the facility layout selection problem, which is always a group decision scenario in enterprises.

The model in this paper works for providing information for decision making, and can be a good reference for further researches related to the model constructions in facility layout selection problems.

1.5 Outline of the Thesis

This research deals with the selection problems in facility layout alternatives. With several developed alternatives, we attempt to make a better, or even the best choice. To achieve this purpose, we first perform a literature review on this topic in Chapter 2. The literature review focuses on three subjects, that is, attributes for comparing facility layout alternatives, quantitative index of attributes and methods for ranking alternatives respectively.

In Chapter 3, we focus on the methods applied to the ranking of alternatives. Two scenarios, single decision maker and multiparticipant decision makers, are considered in this paper. We employ one of the MADM methods in the single decision maker scenario in section 3.1, and one group decision method in section 3.2. At the end of Chapter 3, section 3.3, we give an example to demonstrate the models we proposed. Finally, in Chapter 4, we come to a conclusion of this research. Figure 1.5 is the illustration of the research structure.

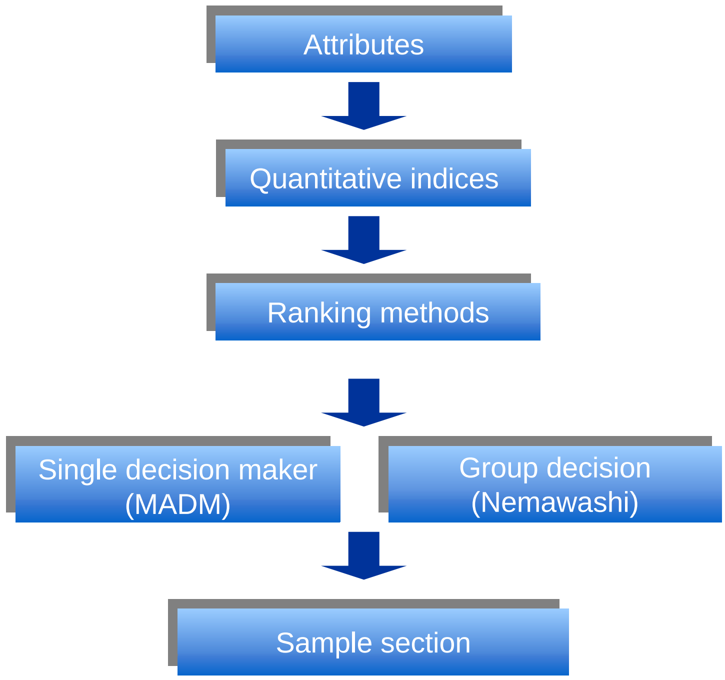


Figure 1.5 The framework of this research

Chapter 2 Literature Review

Facility layout problems are always treated as design problems. Therefore, lots of researches discussed about optimization for single objective, such as minimum equipment invest cost, maximum space utilization, and minimum material handing cost, etc. But for facility layout selections or decision makings, all objectives should be considered.

In order to create a decision support model for facility layout selection problems, we need to review the attributes that should be considered when making decision at first. Then quantitative index for attributes may be needed for judging the ranking of each attribute among all alternatives. Finally, a method that ranks alternatives is certainly necessary for decision making.

According to Lin's study (as cited in Lin and Sharp [11]), we find that researches about facility layout selection are few. Lots of papers studied the facility layout design problems. But only a few papers are about the facility layout selection problems. After reviewing literature in the public, we found that few papers proposed attributes for facility layout selections, and even fewer papers mentioned about quantitative indices and methods to select the best choice from alternatives. For the concerns of this research, we summarize the literature review conclusions with attributes, quantitative indices and alternative ranking methods topics.

2.1 Attributes for Facility Layout Selections

The first problem we encountered when trying to make a selection decision is the attributes needed to differentiate all alternatives. After investigating, we obtained some attributes for facility layout selection.

Francis et al. [5] specified 13 items that can be attributes for ranking facility layout alternatives. The items are as follows:

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.

For judging facility layout alternatives, Muther [12] proposed another set of detailed attributes. The attributes were classified into 20 groups (attributes in each group are listed in Appendix A):

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

Lin and Sharps' study (as cited in Lin and Sharp [10]) also developed a structured attribute set to be the reference of comparison among layout alternatives. It classified 18 attributes into three groups, cost attributes group, flow attributes group and environment attributes group. The attribute set is shown in Table 2.1.

Table 2.1 An attributes set with three groups, seven classes and 18 attributes

Set with three attribute groups, seven attributes 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	Clearness	Aisle	Robustness of equipment capacity	Topography and topology	Human-related safety
	WIP inventory holding cost	Space sufficiency and utilization	Distance and volume density	Building expansion	Community environment	Worker-related comfort
						Property-related security
Annual operation and maintenance cost: ▪ Labor ▪ Utility ▪ Maintenance	Finished goods inventory holding cost					Access for maintenance
Future salvage value						

Source: [10]

We roughly describe the meaning or definition of each attribute as follows:

1. Cost group:

Classified into two classes, non-inventory and inventory. In non-inventory class, initial cost, annual operation and maintenance coat and future salvage value are considered. And in inventory class, mainly take the holding costs of raw material, WIP and finished goods as the indices of cost.

2. Flow group:

Categorized into three classes, space relationship, material flow and robustness and flexibility. There are totally six attributes in this flow group.

(1) Clearness

Attribute clearness is for the extent to which a floor level is free from fixed or permanent building features that affect the effectiveness of space allocation in a layout. Three kinds of building features, partition/wall, column and stair/elevator are investigated here. The reason to examine partition/wall is that it will influence the possible alternatives of department space allocation, ease of future, building expansion, aisle arrangement, and travel distance of material handling activities. As to the column item, it does not disrupt the material flow very much. But it affects the placement of machinery and functional departments in the current setting and in future rearrangements. The stair/elevator item is checked because it affect the handling method employed, travel distance, and space utilization ratio. A stair/elevator in an office building should be in the middle of a floor to provide a good closeness relationship to all employees. In contrast, a stair/elevator in a manufacturing building should be in a corner to increase the degree of clearness. And the area occupied by a stair/elevator can be represented as a partition/wall.

(b) Space sufficiency and utilization

This attribute wants to obtain information about the sufficiency and utilization of space. Not only to provide a definite space for each specific activity or function, we further need to concern if the space is overused or underused. The space is regarded as overused when there is not enough space reserved for future activities. The space is underused when the floor area or cubic space are not fully utilized, and forces the company to lease additional space to satisfy its need.

For judging the sufficiency and utilization of spaces, five main types of space usage must be examined respectively.

a. Space for production machinery (including buffer space between machines) and material handling equipment.

b. Space for storage (including space for receiving material, WIP, finished goods, supplies, salvage, scrap/waste, equipment not in current use, miscellaneous storage, etc…).

c. Space for personnel needs, e.g., office, cafeteria, restroom, etc.

d. Aisle space for material and personnel movement.

e. Free space. Modern industrial plants are constantly undergoing changes, and space as much as 15% of a facility may be reserved for future expansion or layout changes. Sometimes the free space can be temporarily used as WIP/buffer space.

(3) Aisle

Attribute aisle is for the effectiveness of aisle arrangement to support the flow of material/personnel movements among functional departments. To decide an aisle design is good or not, six items are proposed for examining.

a. Area served by the aisle: For different layout alternatives, the total area served by the whole aisle system might be the same, but the aisle length and area occupied are different, or vice versa.

b. Ease of access: the idea for measuring the ease of access is to estimate the minimum number of orthogonal aisles to serve the area so that no point is further than a certain distance from the aisle system.

c. Alternative routes: the idea for alternative routes is to estimate the average number of possible routes that a part can use in a facility.

d. Intersection: In an aisle system a four-way intersection is worse than a three-way intersection from the viewpoint of safety and traffic congestion, although a four-way intersection might be more efficient in providing access.

e. Department shape: for accessibility from outside, long and thin intervening department is not as good as a department of near square shape with the same space. A department of irregular shape would be more difficult to switch use with other departments in future rearrangement and space might be wasted. Therefore, for judging the effect of aisles, we expect no department shape is too long and thin.

f. Straight aisle: aisles that are straight are preferred.

(4) Distance and volume density

This attribute is to estimate the density of material movement among different departments or workstations to support the production requirements. There are three types of movement among different departments:

a. Raw materials, components, and finished products.

b. Paper work

c. Personal travel without carrying material or paper (e.g., the walking distance from workstation to restroom or cafeteria).

Since the total distance in the last two types of movement is usually not significant compared with the first type in an industrial plant, we usually focus on the production material movement. By examining the volume of material moved through the aisles, we can tell if the aisle design is good or not.

(5) Robustness of equipment capacity

Robustness of equipment capacity is to estimate the robustness of the production/material handling equipment to adjust to future changes and satisfy different capacity requirements. Generally, the department layout design precedes the material handling system design and equipment selection, although the latter stages can provide feedback and lead to revision in the previous stage. This precedence relationship restrains the possible choices of material handling systems. Thus, with different facility layout designs, we may have different equipment matching the layout designs. Investigating the flexibility of equipment capacity can offer us important information for making proper facility layout selections.

Three items can be used to verify if the robustness of equipment capacity is proper.

a. Standardization of material handling equipment: This refers to the variety of material handling equipment used. It is preferable to use fewer equipment types, rather than to use specialized equipment for each specific function.

b. Sufficiency of material handling equipment: two points needed to be considered here. First, proper attachments and accessories are required for the material handling equipment to function properly. Second, different types of equipment are needed to satisfy different kinds of actions in the production process.

c. Utilization of material handling equipment: A low utilization ratio implies a waste of investment, while a high utilization might result in a bottleneck or lack of capacity in a peak load period.

(6) Building expansion:

Attribute building expansion is to estimate the ease of expanding the building space, or ease of adding facilities nearby. A layout design with areas available for the building to be expanded is critical for possible layout modifications in the future.

3. Environment group

There are two classes, surrounding and environment quality, in this group.

(1) Surrounding

Two attributes, topography and topology, community environment, are used to verify the surrounding situation of facility layouts. In topography and topology, typically examine three generic circumstances:

a. Natural site conditions and construction

b. Truck access and circulation pattern

c. Connections with external material methods and equipment.

Similarly, three generic circumstances for community environment also:

a. Impact of traffic congestion and noise

b. Waste management and pollution control

c. Appearance of external or viewable features.

(2) Environment quality

For environment quality, four attributes are concerned, human-related safety, worker-related comfort, property-related security and access for maintenance.

From the three sets of attributes mentioned above, we can learn that the attributes cover huge range. From cost, space, material flows, security… even to mental feeling about facility layouts. The main reason to make attribute sets can hardly perfect is that facility layouts cause enormous and various effects on any organizations.

2.2 Qualitative Indices of Attributes

In addition to decide the attributes, another crucial work in selecting layout alternatives is to distinguish the performance of each alternative in every attribute. For the sake of showing the strength or weakness in each attribute objectively, we prefer to build up a qualitative index for each attribute, and let these indices bring us information with less arbitrariness for decision making.

To deal with the quantitative indices problem, Muther [12] suggested a set of rating code to evaluate the advantage or disadvantage of each alternative in every attribute. In every attribute, each alternative is assigned a code, labeled A, E, I, O, U and X, each code here represents a numerical value. Therefore, all alternatives in every attribute can be compared after applying this set of rating code as the qualitative indices. A summarized list of this set of rating code is demonstrated in Table 2.2.

Table 2.2 Muther's rating code

Rating code and values		
Vowel coding	Description of rate	Numerical value
A	Almost perfect (Excellent)	4
E	Especially good (Very good)	3
I	Important results obtained (Good)	2
O	Ordinary results provided (Fair)	1
U	Unimportant results (Poor)	0
X	Not acceptable	?

Source: [12]

After developing the 18 attributes, Lin and Sharp [11] also proposed some qualitative indices for attributes. As we mentioned before, the 18 attributes are classified into cost, flow and environment groups. For the attributes in the cost group, all indices use economic dollar values based on the principles of engineering economy, therefore, there is no need to develop another qualitative indices for cost group attributes. The qualitative indices required are for flow and environment group attributes.

We listed the qualitative indices for the six flow group attributes in Appendix II. As to the environment group attributes, Lin and Sharp proposed a procedure to decide the quantitative index for each attributes. The procedure is as follows:

1. Identify the generic circumstances that are of concern to the facility engineer. Lin and sharp also developed a structure generic circumstance that extended from the environment group attributes in Table 2.3.

2. Identify if any priorities exist among these generic circumstances or if they are equally weighted.

3. Identify the considerations to prevent undesirable results from occurring or enforce the desirable results to happen in each circumstance. However, the details of the considerations may depend on the industry type and the specific case considered.

4. Assign a desired rating of importance to each consideration. The scales of ratings may be 5, 4, 3, 2, and 1 for critically important, strongly important, moderately important, fairly important, and weakly important, respectively. Then, calculate the total desired rating as:

$$\sum_{i} \text{(desired rating } i\text{) (number of considerations in this rating)}$$

5. Estimate the actual rating of importance for each consideration. Estimate total actual rating as:

$$\sum_{i} \text{(actual rating } i\text{) (number of considerations in this rating)}$$

6. Finally, The qualitative index for an attribute is equal to [(total actual

rating)/(total desired rating)].

Table 2.3 A structure generic circumstance of environment attribute group

Structure of environment attribute group						
Surrounding			Environment quality			
Attribute:	Topography and topology	Community environment	Human-related safety	Worker-related comfort	Property-related security	Access for maintenance
Generic circumstance	1. Natural site conditions and construction 2. Truck access and circulation pattern 3. Connection with external material handling methods and equipment	1. Impact of traffic congestion and noise 2. Waste management and pollution control 3. Appearance of external or viewable features	1. Human-building accidents 2. Human-vehicle crossings 3. Human-machine/ material interfaces	1. Lighting 2. Noise 3. Ventilation/ heating 4. Ergonomics 5. Handicapped access	1. Theft from outside the building 2. Theft from within the building 3. Special caution for dangerous areas	1. Compatibility of building construction and material handling equipment 2. Space for maintenance work 3. Location of maintenance activities 4. Complexity of material handling equipment

Source: [10]

Both qualitative indices mentioned above attempt to compare alternatives with exact attribute values. But once numerous alternatives and attributes are considered, some problems may occur. For instance, assigning proper values to every attribute could be a difficult and objective work to Muther's indices. And calculating exact values of each attribute can also be a complex problem to Lin and Sharps' indices.

2.3 Methods for Ranking Alternatives

The Simple Additive Weighting Method is the most often method used to rank alternatives. In Muther's selection method, decision makers should assign weights to attributes, and since the rating code is put in use, we can get a score of each alternative from summing up the multiplications of every attribute's weight and rating code value. Since the scores of alternatives are obtained, we can certainly rank all alternatives, and have perform the selection based on the scores.

Though Lin and Sharp developed detail quantitative indices for attributes, the method they applied to rank alternatives is Simple Additive Weighting Method still. The decision maker assigns weights to attributes, and the alternative with highest score is selected to be the final solution.

Actually, we have many choices while ranking alternatives. Facility layout designs need to satisfy various objectives, and objectives may conflicts with each other. Moreover, for judging each alternative, various attributes need to be considered. So we can treat facility layout selection problems as Multiple Attributes Decision Making (MADM) problems. There are many methods can be applied to solve MADM problems. We will have a further discussing about the MADM and methods in Chapter 3.

Chapter 3 Construction of A Decision Support Model for Facility Layout Selections

In this chapter, we first investigate the general decision making process of facility layout selection problems, and then divide the selection problems into two scenarios, single decision maker and group decision. One of MADM models will be applied in the single decision maker scenario, and also one of group decision making models will be applied in the group decision scenario. We use a sample to demonstrate the models we proposed. In this sample, these two models are included in a complete facility layout selection process, which we regards as close to the real decision process in organizations.

3.1 The General Decision Making Process of Facility Layout Selection Problems

The facility layout selection problems occur when we encounter the request of facility layout designs. In general, IE engineers in companies are responsible for collecting the requirements of this facility layout design from all related departments. After classifying and analyzing all the requirements, IE engineers then develop several possible alternatives. In order to seize potential alternatives out from all the developed alternatives, IE engineers perform cost estimations, advantage-disadvantage analysis for all the developed alternatives. Usually, some candidate alternatives are therefore selected after the analysis in IE department.

Since the facility layout selection problems always relate to various departments, IE's candidate alternatives are then carefully evaluated by many top managers in companies. After the negotiation and persuasion process, one alternative is finally chosen as the consensus plan. As the decision are made, IE engineers then edit a formal document and forward the document for signature and announcement. After the document circulation is completed, the facility layout can be put into practice. But once none of the candidate alternatives is satisfied, IE engineers then need to develop other alternatives again. The decision making process of facility layout selection is summarized in Figure 3.1.

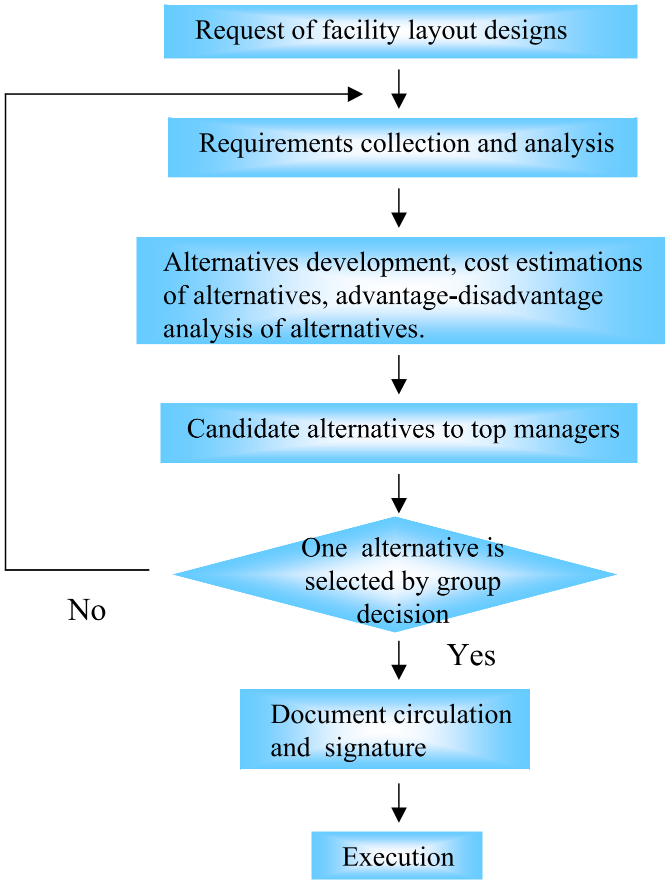


Figure 3.1 The decision making process of facility layout selections

3.2 MCDM, MODM and MADM

Multiple Criteria Decision Making (MCDM) refers to making decisions in the presence of multiple, usually conflicting, criteria. Problems for multiple criteria decision-making are common in daily life. The problems of MCDM are widely diverse. However, even with the diversity, all the problems share the following common characteristics:

1. Multiple objectives or attributes: each problem has multiple objectives or attributes. A decision maker must generate relevant objectives/attributes for each problem setting.

2. Conflicting among criteria: Multiple criteria usually conflict with each other.

3. Incommensurable units: each objective/attribute has a different unit of

measurement.

4. Design or selection: solutions to these problems are either to design the best alternatives or to select the best one among previously specified finite alternatives.

The problems of MCDM can be broadly classified into two categories in this respect: Multiple Attribute Decision Making (MADM) and Multiple Objective Decision Making (MODM). In practice, this classification is well fitted to the two aspects of problem solving, MADM is for selection (evaluation), and MODM is for design.

The distinguishing feature of the MADM is that there are usually a limited number of predetermined alternatives. The alternatives have associated with them a level of the achievement of the attributes based on which the final decision is to be made. The final selection of the alternative is made with the help of inter- and intra-attribute comparisons. The comparisons may involve explicit or implicit tradeoff [8].

As treating the facility layout selection problem as a MADM problem, we certainly should investigate the models that solve the MADM problems. Hwang and Yoon [8] summarized the MADM models as in Figure 3.2.

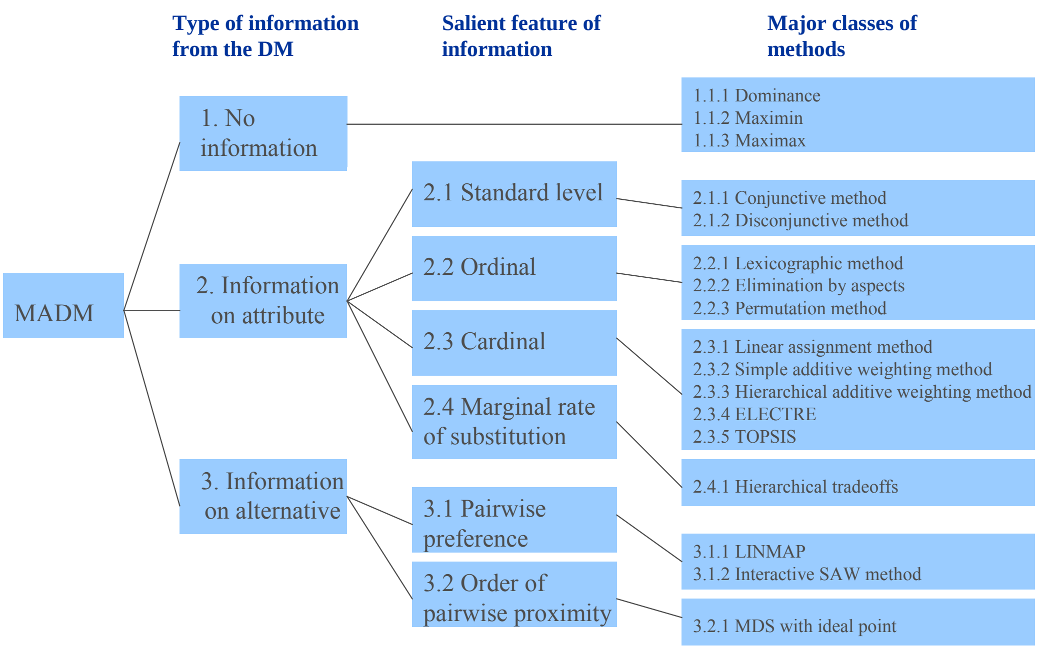


Figure 3.2 The summary of MADM methods

3.3 Linear Assignment Method

Bernardo and Blin developed Linear Assignment Method to deal with consumer choice among multi-attributed brands [2]. Compared with other methods in MADM, this method possess characteristics as follows [8]:

1. The method is based on a set of attributewise rankings and a set of attribute weights.

2. The method features a linear compensatory process for attribute interaction and combination.

3. In the process only ordinal data, rather than cardinal data, are used as the input. Thus we do not need to scale the qualitative attributes.

3.3.1 Product-attribute matrix

The linear assignment method first define a product-attribute matrix π as a square (m╳m) nonnegative matrix. The elements π_{ik} represent the frequency (or number) that alternative i (A_i) is ranked the k_{th} attributewise 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

Then we can create the π matrix:

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

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

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

In addition, if an attribute is tied in the rank:

Rank	$X_1\,(w_1)$	$X_2\,(w_2)$	$X_3\,(w_3)$
1_{st}	A_1, A_2	A_1	A_2
2_{nd}		A_3	A_1
3_{rd}	A_3	A_2	A_3

Then, it can be equalized as:

Rank	$X_{11}\,(1/2\ w_1)$	$X_{12}\,(1/2\ w_1)$	$X_2\,(w_2)$	$X_3(w_3)$
1_{st}	A_1	A_2	A_1	A_2
2_{nd}	A_2	A_1	A_3	A_1
3_{rd}	A_3	A_3	A_2	A_3

3.3.2 LP Model

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

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

This is an m! comparison problem. A LP model is suggested for the case of large m.

Now we define a permutation matrix P as (m╳m) square matrix. Element P_{ik} =1 if A_i is assigned to overall rank k, and P_{ik} =0 otherwise.

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

$$Max \sum_{i=1}^{m} \sum_{k=1}^{m} \pi_{ik} p_{ik}$$

$$\text{s.t.} \quad \sum_{k=1}^{m} p_{ik} = 1, \qquad \text{i} = 1, 2, ..., \text{m}$$

$$\sum_{i=1}^{m} p_{ik} = 1 \qquad \text{k} = 1, 2, ..., 8$$

$$p_{ik} \geq 0 \qquad \text{for all i and k}$$

Finally, let the optimal permutation matrix, which is the solution of the above LP problem, be P*. Then the optimal ordering can be obtained from A ╳ P*.

To deal with facility layout selection problems with Linear Assignment Method, we therefore can avoid the necessary to build up detail qualitative indices, and the difficulty of assigning exact values to attributes. To rank alternatives in each attribute is easier than to define proper qualitative indices, or to decide exact values for attributes afterwards.

3.4 Multiparticipant Decision Making

When there are multiparticipant decision makers, we generally regard the decision making as a group decision. Guzzo [6] mentioned about the importance of group decision study. He proposed that the study of group decision making is both fascinating and important. It is fascinating because the action of the decision making groups can be puzzling and unpredictable. It is important because this action often has significant consequences. Group decision making in government and industry, for example, can influence our lives in many ways, such as through the establishment of laws and rules and the determination of how much we are paid for our work.

Holsapple and Whinston [7] summarized the decision making patterns according to the quantity of decision makers as in Figure 3.3.

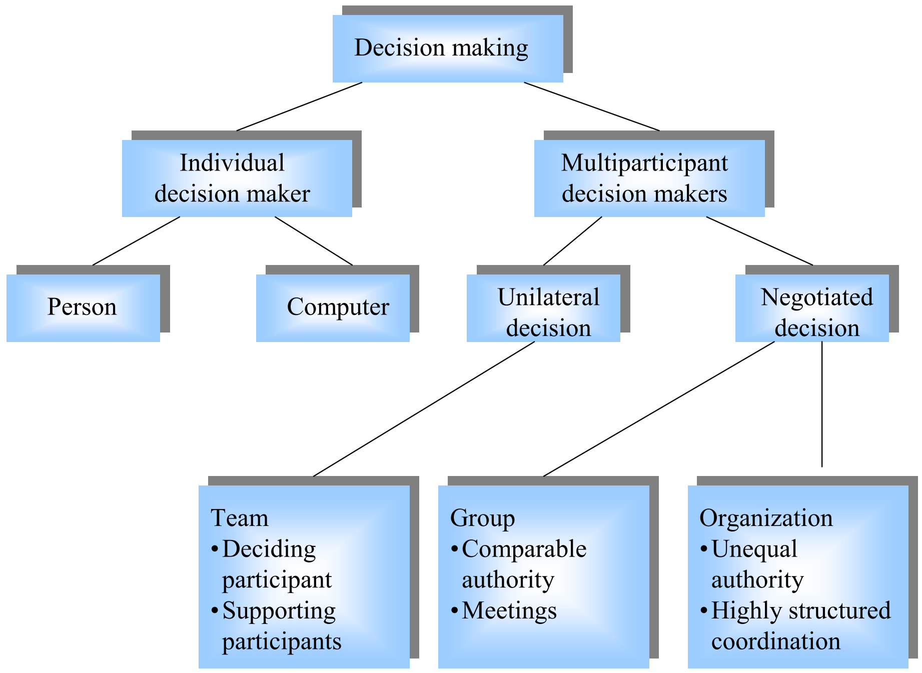


Figure 3.3 Types of decision makers

In the individual case, the decision maker is a person or a computer system. In the multiparticipant case, we have either a unilateral decision or a negotiated decision.

In making a unilateral decision, one of the multiple participants is vested with the power to decide. Although the others do not have the power to decide, they can strongly influence what the decision will be and how efficiently it will be manufactured. They do so by carrying out tasks that the deciding participant assigns to them during the course of making the decision. We can think of them as being supporting participants. We call this kind of multiparticipant decision makers a team.

In making a negotiated decision, multiple participants share decision making authority. One common decision maker of this type is a group, where the participants have comparable authority with respect to the decision. The group typically has meetings to conduct discussions that lead to eventual agreement about committing to a course of an action.

Compared with group decision maker, organization decision maker has highly structured patterns of communication among participants, clear acknowledge of distinct authority levels, and established policies for coordinating participants activities.

The distinguishing traits among these four types of decision makers are summarized in Table 3.1.

Table 3.1 Multiparticipant decision makers: distinguishing traits

DISTINGUISHING TRAINTS	DECISION MAKERS			
	Individual	Team	Group	Organization
Participants	One	Multiple	Multiple	Multiple
Authority	Vested in one person	Vested in one person (deciding participants)	More or less equality shared by all participants	Can be distributed unequally among participants
Formal communication among participants	None	Relatively structured	Relatively few restrictions	Can be quite structured
Division of decision making labor	No division of labor	Division of labor among specialists (supporting participants)	Relatively little division of labor	Can be extensive division of labor and specialization
Duration	Ongoing	Often ongoing, but can be limited	Often limited (e.g., to scope of one decision) but can be ongoing	Ongoing

Source: [7]

As to the methods for executing multiparticipant decision making, Hwang and Lin [9] proposed a summary as in Figure 3.4.

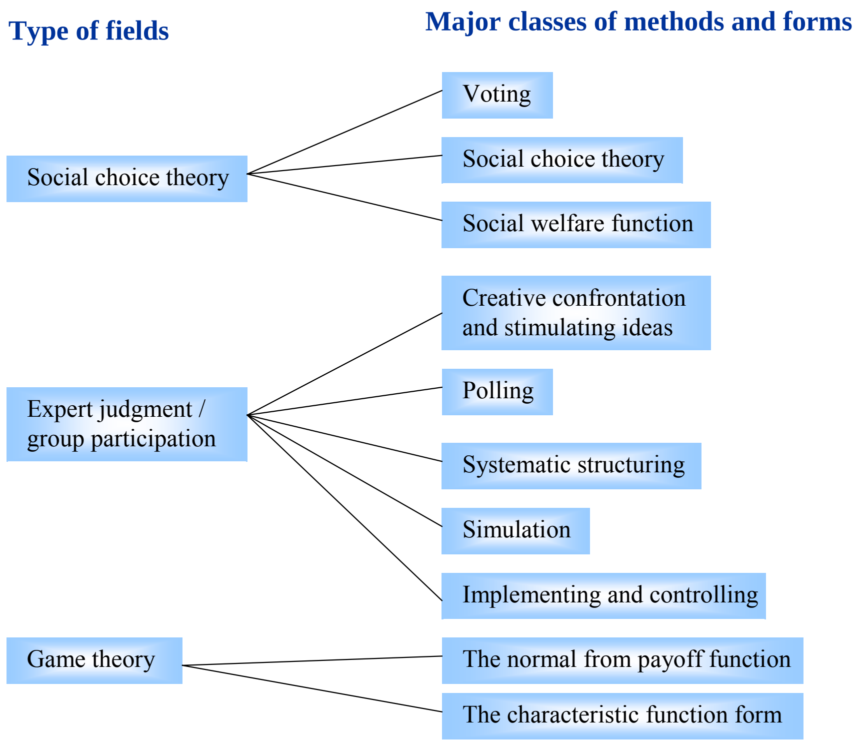


Figure 3.4 Methods for multiparticipant decision making

3.5 The Nemawashi Model

Watabe, Holsapple and Whinston [16] proposed a Nemawashi model for multiparticipant decision making problems. For discovering that the decision making process in Japanese organizations is different from that in western ones, they look into the Japanese decision making, and developed such a model.

3.5.1 Japanese Decision Making

In American and European organizations, decision making tends to be relatively individualistic or autocratic, and handled by only a few decision makers, although the decision may related to many decision participants. But in the Japanese style of decision making, all people related to the decision participate in the decision process, and contribute notable influences to the decision. Ouchi's study (as cited in Watabe, Holsapple and Whinston [16]) showed that the number of decision participants in Japanese is usually between four to ten, but for important decisions it may be as high as 60 to 80.

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

After success in gaining a consensus, the coordinator prepares a formal document with detail information of the proposal, and circulates it among the participants for consent. This document circulation stage of decision making is called ringi.

According to the opinion from Watabe, Holsapple and Whinstons, the advantages and disadvantages of the Nemawashi-ringi approach are as follows. For the advantages:

1. Many person's participation leads to better quality decisions, easier implementation, and higher morale than non-consensus choice.
2. Risk-taking (or responsibility) is shared
3. Each participant can take time to think through the proposal
4. Each participant's wishes may be incorporated in the decision

And the disadvantages that have been observed include:

1. As the coordinator needs to consider many persons' opinions, it can be difficult for the coordinator to select an appropriate proposal from candidate alternatives.
2. As the coordinator should negotiate with and persuade other participants for gaining a consensus, and circulate the ringi document sequentially, much effort and considerable time is required before a final formal decision is made.
3. As it is difficult to find direct relations between each persons' support of the plan and individual opinions for complicated problems, the coordinator does not know about which points and who are needed to perform the negotiations, compromise or persuasions.

The model developed attempts to improve the disadvantages mentioned above, thus brings the Nemawashi approach become more profitable.

3.5.2 The Path Toward Consensus

Watabe, Holsapple and Whinstons' research also described the steps taken to gain a consensus and make a formal decision in Japanese organizations.

The first step is information collection. When a requirement of decision making raises, a person or a small team is then assigned the work of coordinator to handle this project. The coordinator need identify the persons related with this decision, and gather their opinions about this decision.

The second step is data analysis and plan generation. After obtaining the opinions, the coordinator analyzes these data and develops candidate plans. The coordinator may evaluate all the plans in advance, by experts' opinions or some criteria, and then decides some alternatives as proposals.

The third step is plan selection. After considering all decision participants' opinions, the coordinator selects an alternative as the proposal for Nemawashi.

The fourth step comes the negotiation and persuasion (Nemawashi). The coordinator makes an informal document of the selected proposal, then negotiate with all decision participants. If the proposal fails to reach a consensus, then the coordinator revises the proposal, and repeats the Nemawashi again. Step 3 and step 4 are repeated iteratively until the consensus is obtained.

The Final step is document circulation (ringi). A formal document of the consensus is prepared and circulates to all the decision participants for a formal approval.

From information gathering, coordinator assignment, data analysis and alternatives generation, plan selection and then document circulation, we find that the decisions of facility layout selections follow the steps well. We usually find that Industrial Engineering engineers be assigned the role of coordinators, responsible for facility layout design base to expects or opinions from top managers, negotiate with all related members, then select a plan for carrying out. The negotiation process needs lots of time to reach a consensus for facility layouts always cause huge influences on every organization.

3.5.3 The Nemawashi Model

Watabe, Holsapple and Whinstons' model is mainly constructed by some components as follows:

1. Preparatory Matrices

The coordinator should prepare some matrices that carry information:

a. Plan evaluation matrix E

Plan evaluation matrix shows an evaluation of each plan on each attribute. The element e_{ij} is the evaluation of the i_{th} plan with respect to the j_{th} attribute.

b. Individual criteria priority matrix C

This matrix shows each participant's weight for each criterion. The element c_{ij} of C is an indication of how important criterion i is to participant j

c. Individual influence vector I

One participant's influence on a decision is often different from that of another participant, depending on position, status, expertise, and so forth. The element i_j of I denotes the influence of the j_{th} participants.

d. Individual persuasion difficulty vector P

When the participants' preferences and opinions are so different that they favor different plans, the coordinator uses the art of persuasion in order to gain a consensus on a plan. The element p_j of P denotes the persuasion difficulty for the j_{th} participant

2. Plan selection support

The coordinator could generate some more information by assembling the matrices above:

a. Supported plan matrix S, S=EC:

Matrix S reduces the evaluation of a plan to a single number for each participant, based on evaluation of the plan for the attributes and the participant's priority for the attributes.

b. Consensus matrix S(A), S(A)=EC(A):

The resultant S(A) is an S matrix for which every participant gives plan A the highest approval. By finding a C(A) and S(A), the coordinator is simulating for gaining a consensus on plan A.

c. Difference of preferences D(A):

This matrix is the difference between the initial, or the real, C and a target priority matrix used to produce S(A). D(A) shows where and by what amount the initial C would need to be changed to reach a consensus on plan A.

3. Weighting strategies

For considering the influence of matrix C, I and P in our selection process, we can have four weighting strategies: weight by attributes only (C), weight by attributes and individual influence (C and I), weight by attributes and individual persuasion difficulty (C and P) and weight by attributers, individual influence and individual persuasion difficulty (C, I, P).

Since different weighting strategy leads to variance in the plan selection process, the coordinator could choose one of it according to the characteristics of the organization and decision project.

4. Plan selection strategy

In Japanese organizations, not only selecting the objectively best plan is important, but also selecting a plan that is approved by all the participants and easily to be implemented. 6 plan selection strategies are proposed as follows:

a. Least sum of preference difference

This strategy is to select a plan that keeps the total dissatisfaction of the participants at a minimum. There are four variants of this selection strategy: least sum of preference difference, least sum of preference difference weighted by individual influence, least sum of preference difference weighted by persuasion difficulty and least sum of preference difference weighted by individual influence and persuasion difficulty.

b. Majority

Majority rule is a common method for selecting a plan after sufficient discussions of project or problems for some organizations. But in Japanese organizations, majority rule may serve as a method for last resort when there is no enough time for negotiation, persuasion and compromise. There are four variants in this strategy: Simple majority, majority weighted by individual influence, majority weighted by persuasion difficulty and majority weighted by individual influence and persuasion difficulty.

c. Minimum of maximum preference difference

This rule chooses a plan needed the least preference change for the least satisfied participant. Coordinators choose this rule mainly in order to achieve consensus. Four variants are included in this strategy: minimum of maximum preference difference, minimum of maximum preference difference weighted by individual influence, by persuasion difficulty, and by individual influence and persuasion difficulty.

d. Minimum dissatisfaction exceeding a threshold

This rule is applied to avoid the difficulty, considerable time and effort for persuading strongly dissatisfied participants. Therefore, we set a strategy to select a plan that minimizes the sum of extreme dissatisfaction margin that exceed a certain threshold of dissatisfaction. There are four variants also in this strategy: minimum dissatisfaction exceeding a threshold, minimum dissatisfaction exceeding a threshold weighted by individual influence, by persuasion difficulty, and by individual influence and persuasion difficulty.

e. Minimum sum of dissatisfaction excluding un-persuadable participants

This strategy is for a situation that the coordinator is willing to give up persuading a few participants with strong dissatisfaction. Similarly, four variants presented: minimum sum of dissatisfaction excluding un-persuadable participants, minimum sum of dissatisfaction excluding un-persuadable participants weighted by individual influence, by persuasion difficulty, and by individual influence and persuasion difficulty.

To select one of the strategies, the coordinator could do the choice depends on private preference or project situation.

Chiou, Kao and Lu [3] summarized the Nemawashi model and process as in Table 3.2 and Figure 3.5. The weighting strategy applied here is weight by attributes and individual influence (C and I), and the plan selection strategy selected is least sum of preference difference weighted by individual influence. For selecting facility layout alternatives, we can apply this model on making the selection decision.

Table 3.2 Data required for Nemawashi coordinator

Data	Definition	Specification
Plan 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,…,h j: attributes, j= 1,2,3,…,g e_{ij} : the value of alternative i in attribute j, $e_{ij} \geqq 1$.
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,…,g k: decision makers, k= 1,2,3,…,p c_{jk}: the weight that decision maker k put on attribute j, $1 \leqq c_{jk} \leqq 10$. Assumption: $\sum_j c_{j1} = \sum_j c_{j2} = \ldots = \sum_j c_{jp}$
Individual influence vector I	Decision makers are representatives from different departments, and therefore stand for different influence on	k: decision makers, k= 1,2,3,…,p I_k: the influence of decision maker k, $I_k \geqq 1$.

	decision.	
Plan 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,…,h k: decision makers, k= 1,2,3,…,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…h), find out a C(A) that all decision makers prefer alternative A (i.e. $S_{Ak}(A) \geqq S_{ik}(A)$).	Both try and error method and linear programming method can be applied to find out a C(A) to every A. Suppose $k \in A$ denotes the decision makers that prefer A, and $k \notin A$ denotes the decision makers that aren't prefer A, then the LP model is as follows: $Min \sum_i \sum_k \lvert c_{ik}(A) - c_{ik} \rvert$ $s.t.\ s_{Ak}(A) \geq s_{ik}(A)$ $\sum_j c_{j1}(A) = \sum_j c_{j2}(A) = ... = \sum_j c_{jp}(A)$ $c_{jk \notin A}(A) \leq 10$ $c_{jk \notin A}(A) \geq 1$ $c_{jk \in A}(A) = c_{jk \in A}$
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…,g k: decision makers, k= 1,2,3,…,p $p_{jk}(A) = \lvert c_{ik}(A) - c_{jk} \rvert$

Source: [3]

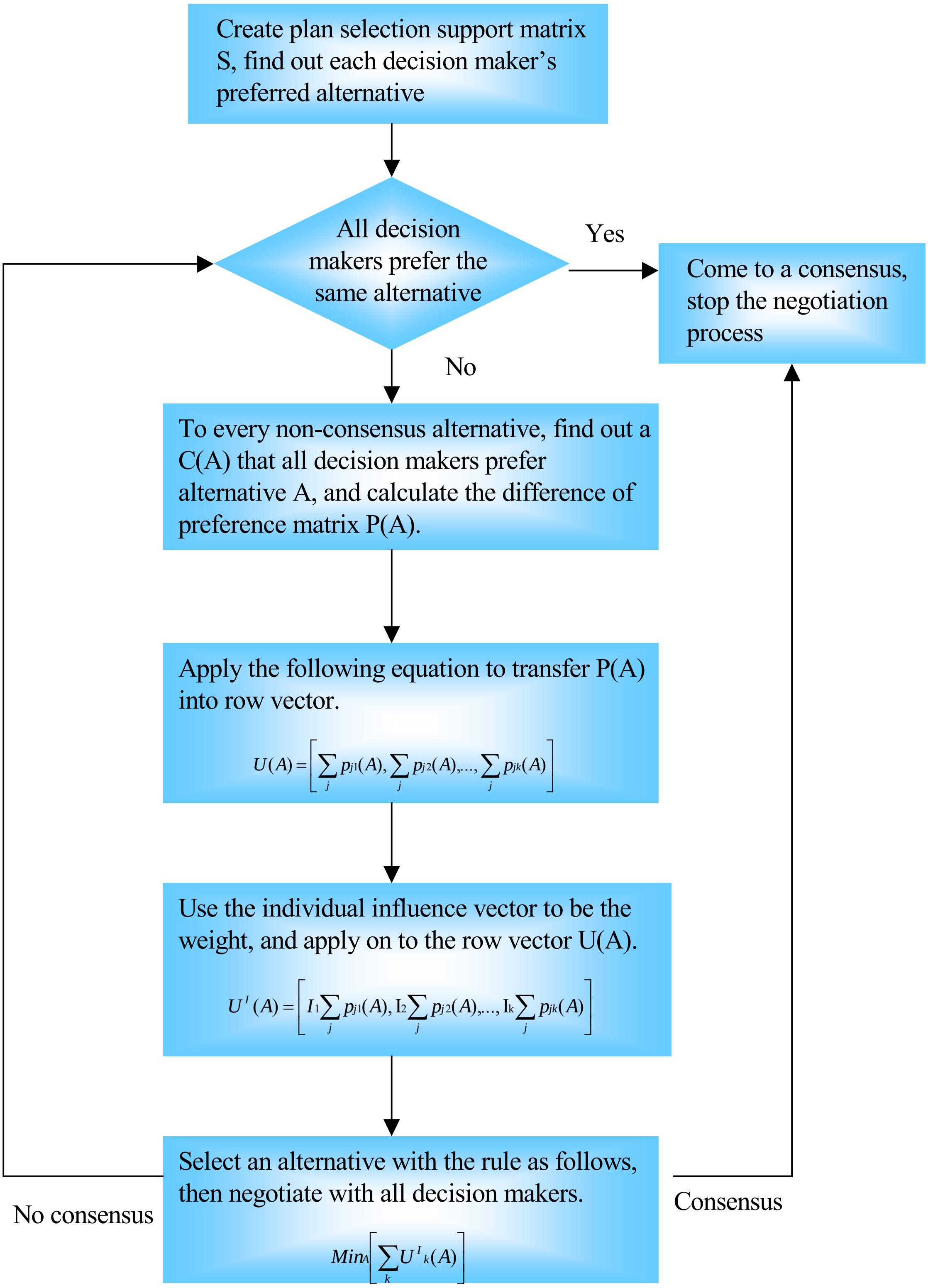


Figure 3.5 Nemawashi process

3.6 A Sample Section

Here we use a sample to demonstrate the decision support model for selecting facility layout alternatives.

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

The IE engineer develops lots of alternatives, and sieves out eight possible plans, labeled A, B, C, D, E, F, G, H, respectively, to be the alternatives. The eight alternatives are illustrated in Figure 3.6.

The characteristics and differences between these eight alternatives are basically summarized as follows:

In Plan A, the material warehouse and the rest room are outside the production area, and locate at the right side and up side respectively. The burn-in room sites in the middle of the production area, and 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. In Plan B, the burn-in room is designed aside the production area. In Plan C, the assembly operation conveyor is a 24 meters loop-flow conveyor. The conveyor is a second-hand conveyor, thus the purchasing cost is lower. In Plan D, there is no aisle beside the burn-in room, and the total production area is smaller. Plan E, the material warehouse is inside the production area, and there is no aisle besides the burn-in room. Plan F, the material warehouse is inside production area, and the burn-in room is designed aside the production area. Plan G, material warehouse is inside the production area, the rest room is designed to locate at the right side, there is no aisle besides burn-in room. In Plan H, material warehouse is inside the production area. The rest room locates at the right side, and the burn-in room is aside the production area.

As standing on more specific and technical viewpoints, the IE engineer applies the 18 attributes set and liner assignment method to rank these eight alternatives.

After examining the eight alternatives with the 18 attributes, some attributes are abandoned for unobvious difference in these alternatives. The attributes taken in this sample are initial cost, annual operation and maintenance cost, Clearness, Space sufficient and utilization, aisle, distance and volume density and work related comfort. Suppose the decision maker sets the weight to every attribute in sequence as 0.15, 0.15, 0.1, 0.2, 0.1, 0.2 and 0.1, and rank the eight alternatives in every attribute as follows:

Initial cost: C, GE, HF, D, A, B

Annual operation and maintenance cost: D, HG, EF, ABC

Clearness: B, A, HF, C, D, GE

Space sufficient and utilization: B, A, C, FH, EG, D

Aisle: B, AC, FH, D, EG

Distance and volume density: EG, AC, D, FH, B

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.

The weighting of attributes and the ranking of alternatives in each attribute are also illustrated in Table 3.3.

Then we can obtain the π matrix as:

$\pi =$

	1_{st}	2_{nd}	3_{rd}	4_{th}	5_{th}	6_{th}	7_{th}	8_{th}
Plan A	0	0.475	0	0.05	0.15	0	0	0
Plan B	0.4	0.025	0	0.05	0.2	0.15	0	0
Plan C	0.15	0.175	0.2	0.15	0	0	0	0
Plan D	0.15	0	0.2	0.3	0.1	0.2	0	0
Plan E	0.1	0.075	0.075	0.05	0.15	0.05	0	0
Plan F	0	0.025	0.25	0.2	0	0	0	0
Plan G	0.1	0.15	0.1	0	0.15	0.05	0	0
Plan H	0.1	0.075	0.175	0.2	0	0	0	0

And the LP model is

$$Max \sum_{i=1}^{8} \sum_{k=1}^{8} \pi_{ik} p_{ik}$$

$$\text{s.t.} \quad \sum_{k=1}^{8} p_{ik} = 1, \qquad \text{i} = 1, 2, ..., 8$$

$$\sum_{i=1}^{8} p_{ik} = 1 \qquad \text{k} = 1, 2, ..., 8$$

$$p_{ik} \geq 0 \qquad \text{for all i and k}$$

With the linear programming software LINGO, we can obtain the solution of this LP model is (the LINGO program and the solution are illustrated in Appendix III):

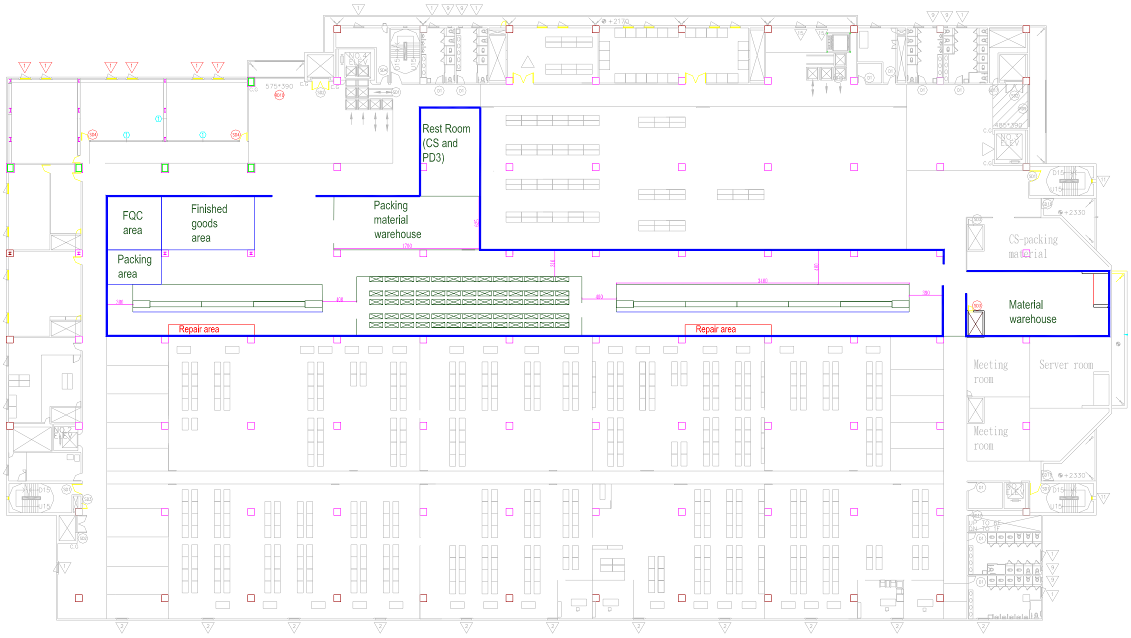
$$P^* = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Finally, the IE engineer gets the optimal alternative ranking as:

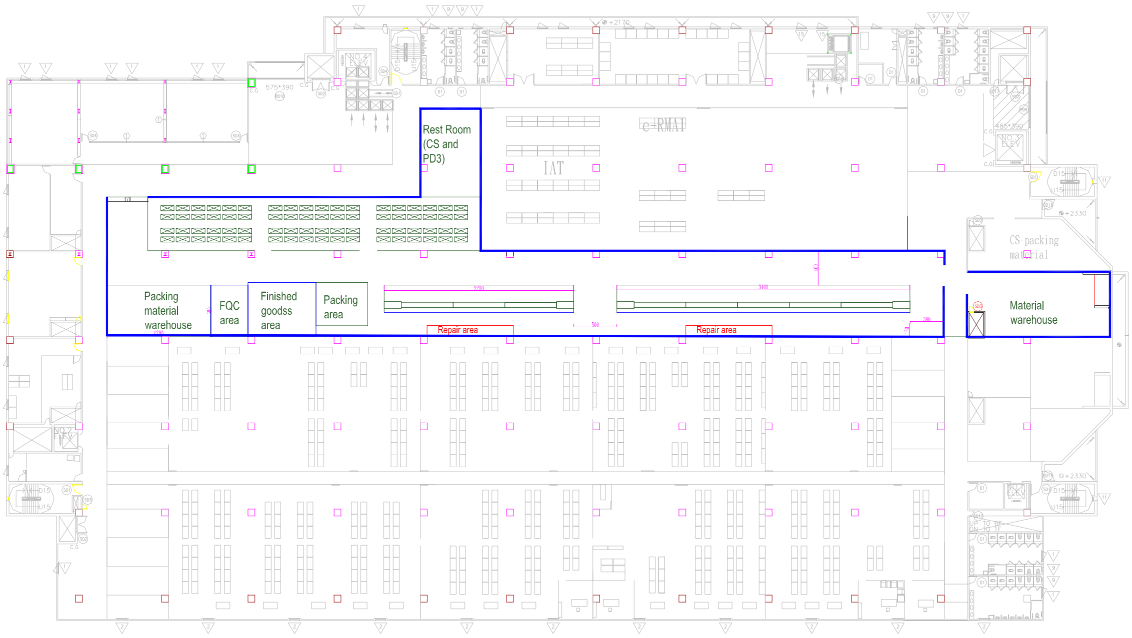
A ╳ P* = (Plan B, Plan A, Plan F, Plan H, Plan E, Plan D, Plan C, Plan G)

After considering the similarity between alternatives, the IE engineer select Plan B, A, F, H to be candidates in group decision.

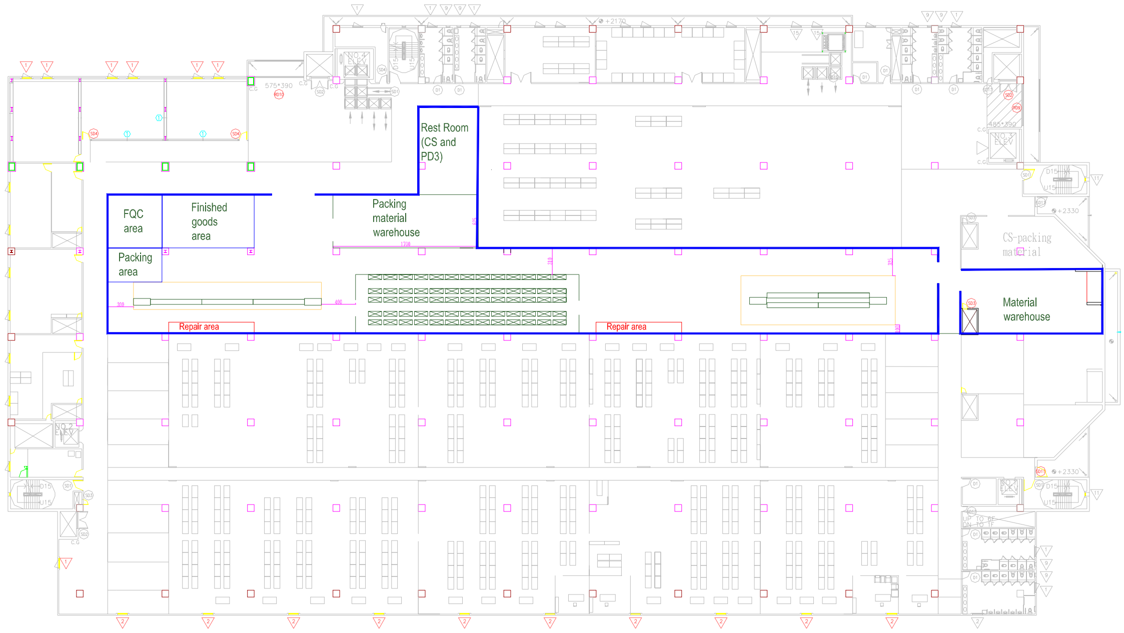
Layout Plan A



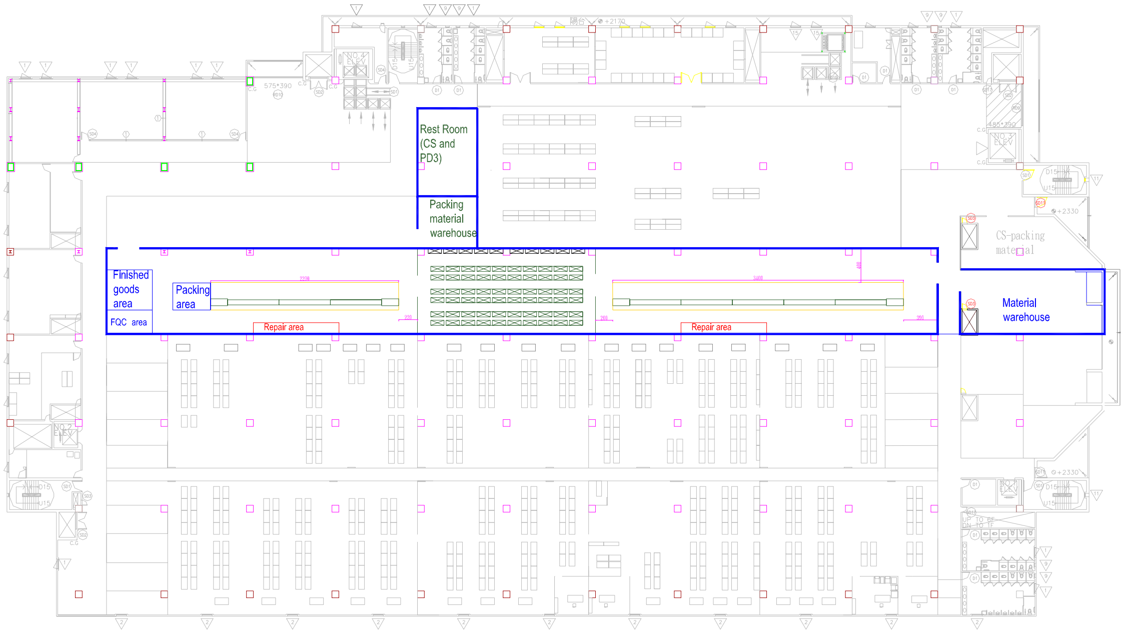
Layout Plan B



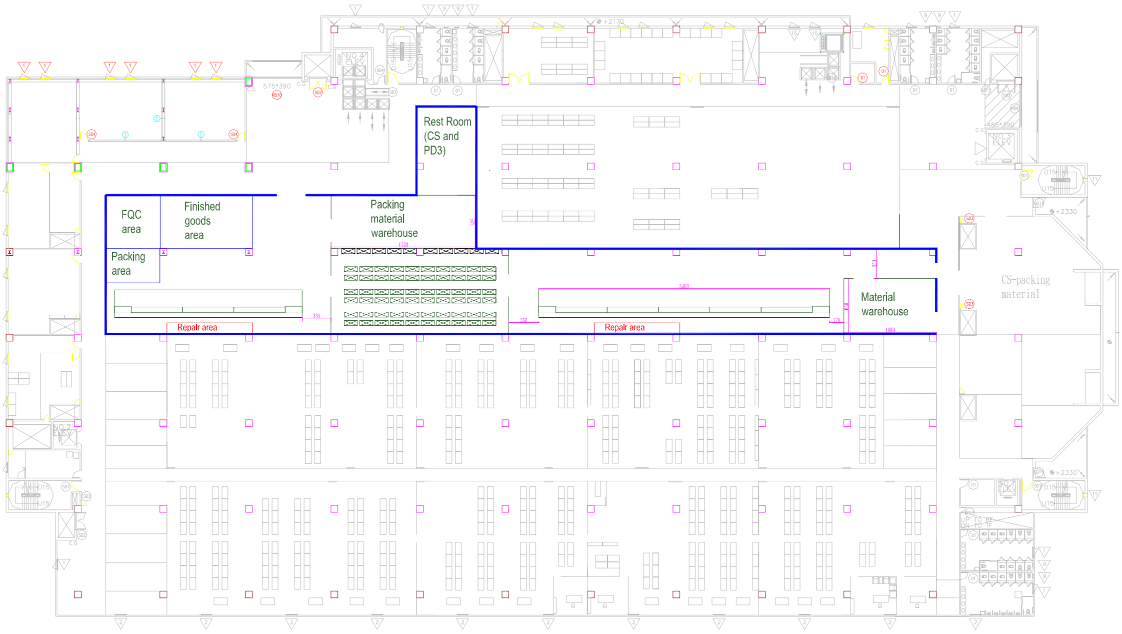
Layout Plan C



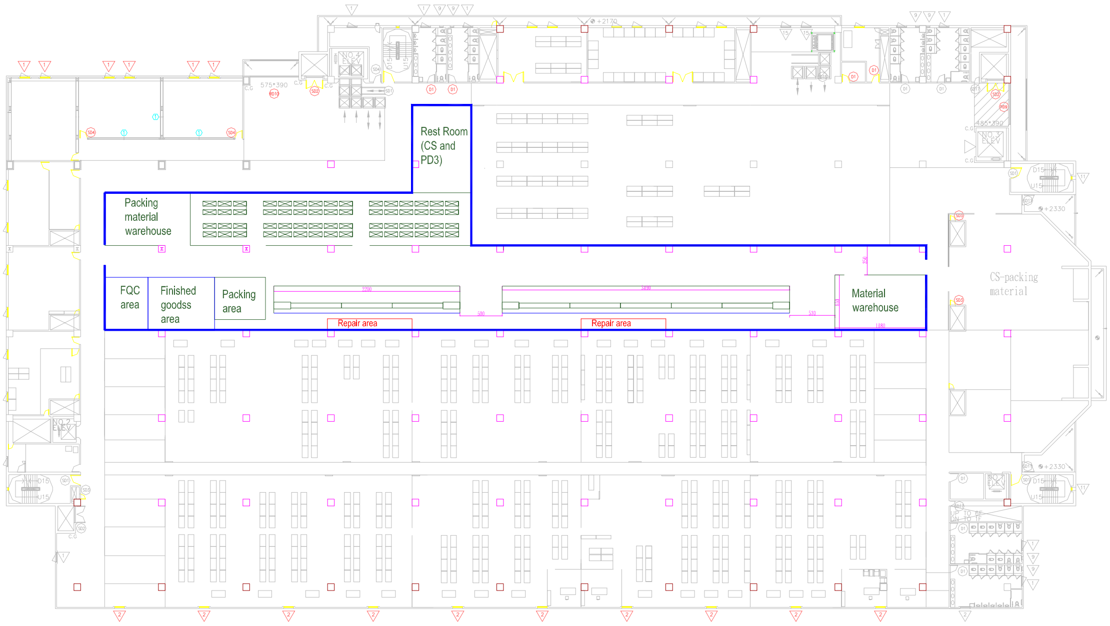
Layout Plan D



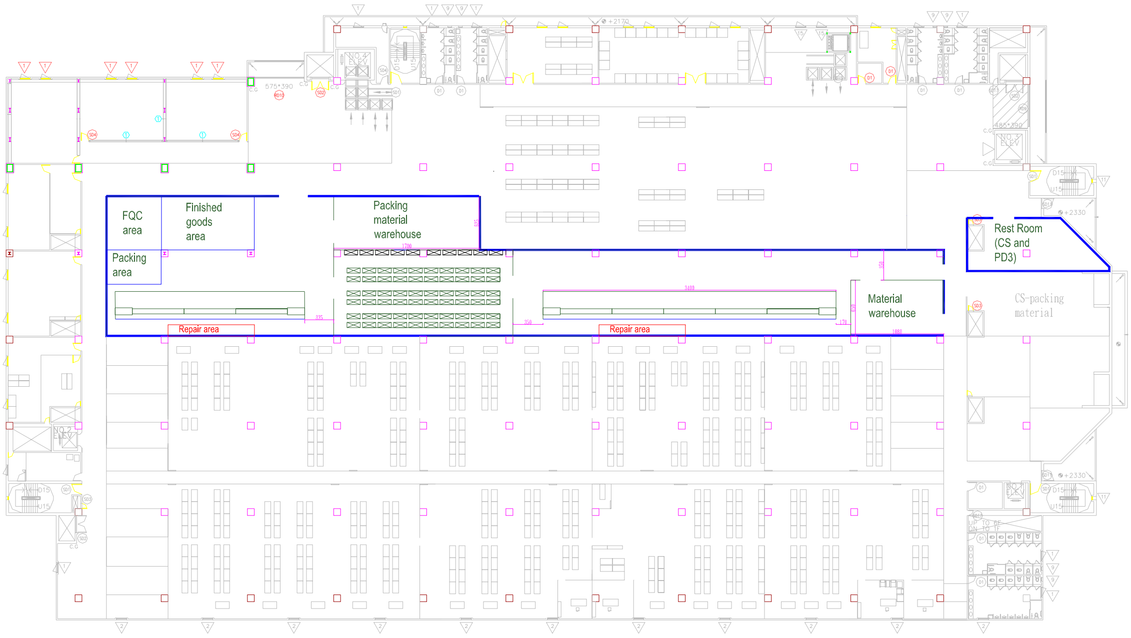
Layout Plan E



Layout Plan F



Layout Plan G



Layout Plan H

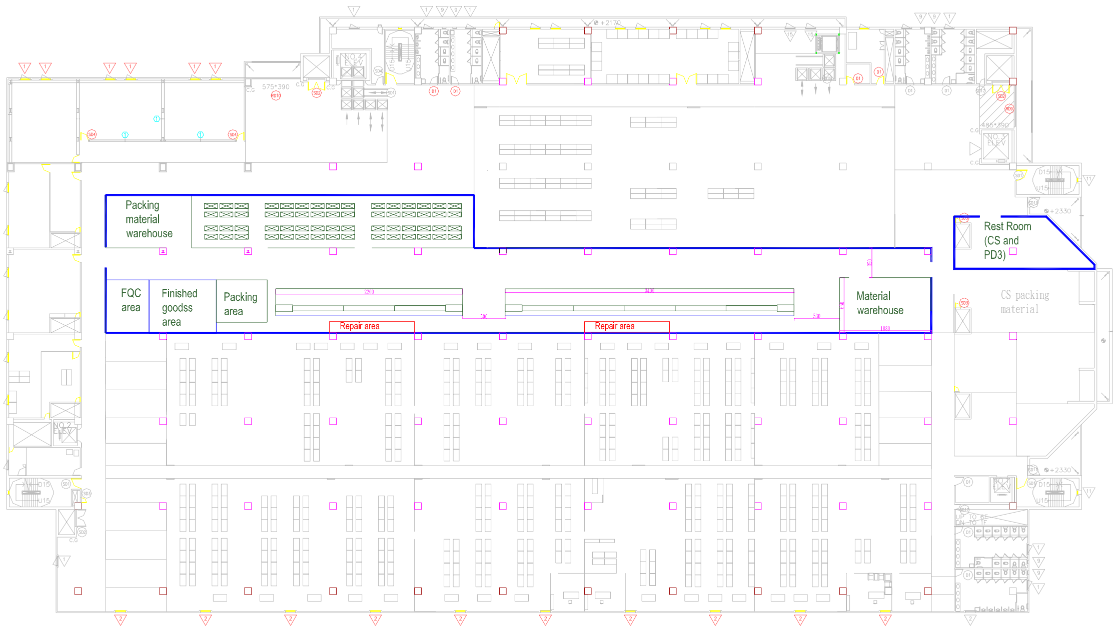


Figure 3.6 Eight facility layout alternatives

Table 3.3 The weighting of attributes and ranking of alternatives

Set with three attribute groups, seven attributes classes and 18 attributes

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 GE HF D A B — Initial cost: 0.15 ▪ Land ▪ Building ▪ Production Machinery ▪ Material Handling equipment	Raw materials inventory holding cost	Clearness 0.1 — B A HF C D GE	Aisle 0.1 — B AC FH D EG	Robustness of equipment capacity	Topography and topology	Human-related safety
	WIP inventory holding cost	Space sufficiency and utilization 0.2 — B A C FH EG D	Distance and volume density 0.2 — EG AC D FH B	Building expansion	Community environment	Worker-related comfort 0.1 — H FCBA G ED
D HG EF ABC — Annual operation and maintenance cost: 0.15 ▪ Labor ▪ Utility ▪ Maintenance	Finished goods inventory holding cost					Property-related security
Future salvage value						Access for maintenance

In Company U, several managers are related to this LCDTV facility layout project and therefore are participants in this selection decision. These participants are Manufacturing Division manager (MD head), Production Department manager (PD head), Business Division manager (BD head), IE Department manager (IE head) and Quality Assurance Division manager (QA head).

Since top managers do decision making with more strategic concerns, the IE engineer applies Muther's 20 attributes set as the attributes in this group decision making. Similarly, only attributes that are capable of distinguishing these four candidates are chosen here. The attributes picked here are 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 interior discussing with all IE partners, the IE engineer creates the plan evaluation matrix E (set $\sum_{j=1}^{4} e_{ij} = 20, \quad i = 1, 2, ..., 6$ and $1 \le e_{ij} \le 10$):

$$
E = \begin{array}{c} \text{Plan B} \\ \text{Plan A} \\ \text{Plan F} \\ \text{Plan H} \end{array}
\overset{\begin{array}{cccccc} \text{Flexibility} & \text{Quality} & \text{Flow} & \text{Space} & \text{Appearance} & \text{Employee} \end{array}}{\begin{bmatrix} 9 & 5 & 3 & 10 & 4 & 4 \\ 3 & 9 & 9 & 6 & 10 & 4 \\ 4 & 3 & 4 & 2 & 3 & 3 \\ 4 & 3 & 4 & 2 & 3 & 9 \end{bmatrix}}
$$

The individual criteria priority matrix C can also be created after interviewing all participants. Suppose the matrix C is (set $\sum_{k=1}^{6} c_{jk} = 20, \quad j = 1, 2, ..., 5$ and $1 \le c_{jk} \le 10$):

$$
C = \begin{array}{c} \text{Flexibility} \\ \text{Quality} \\ \text{Flow} \\ \text{Space} \\ \text{Appearance} \\ \text{Employee} \end{array}
\overset{\begin{array}{ccccc} \text{MD} & \text{PD} & \text{BD} & \text{IE} & \text{QA} \end{array}}{\begin{bmatrix} 5 & 1 & 1 & 6 & 2 \\ 4 & 4 & 6 & 2 & 10 \\ 2 & 2 & 1 & 4 & 2 \\ 5 & 7 & 5 & 4 & 2 \\ 2 & 2 & 6 & 2 & 2 \\ 2 & 4 & 1 & 2 & 2 \end{bmatrix}}
$$

So, the selection support matrix S comes to be:

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

From the S matrix, we see that Plan F and Plan H can be eliminated for no participant prefers these two plans. And since two participants prefer Plan B, three participants prefer Plan A, we need to develop a new C(B) and C(A) respectively for making Plan A or B the final consensus plan.

Searching for the closest C(B) and C(A) to the original C, we are actually solving the LP model as follows:

$$Min\sum_{k=1}^{5}\sum_{j=1}^{6}\left| C_{jk}(x) - C_{jk}\right|$$

s.t. $$S_{xk}(x) \geq S_{ik}(x)$$

$$\sum_{j=1}^{6} C_{j1}(x) = \sum_{j=1}^{6} C_{j2}(x) = \sum_{j=1}^{6} C_{j3}(x) = \sum_{j=1}^{6} C_{j4}(x) = \sum_{j=1}^{6} C_{j5}(x)$$

$$C_{j,\, k \notin x}(x) \leq 10$$

$$C_{j,\, k \notin x}(x) \geq 1$$

$$C_{j,\, k \in x}(x) = C_{j,\, k \in x}$$

members prefer Plan X denoted $k \in x$

With LINGO, we can solve the model and got C(A) and C(B) (the LINGO program and solving result are illustrated in Appendix III):

C(A) =

	MD	PD	BD	IE	QA
Flexibility	4.17	1	1	5.33	2
Quality	4.00	4	6	2.00	10
Flow	2.16	2	1	4.29	2
Space	5.00	7	5	4.00	2
Appearance	2.67	2	6	2.37	2
Employee	2.00	4	1	2.00	2

C(B) =

	MD	PD	BD	IE	QA
Flexibility	5	1.03	4.62	6	6.03
Quality	4	3.98	6.00	2	8.04
Flow	2	1.90	1.00	4	1.00
Space	5	7.59	4.66	4	2.00
Appearance	2	1.52	2.72	2	1.00
Employee	2	3.98	1.00	2	1.94

So with C(A) and C(B), we can obtain the consensus S(A) and S(B) as:

S(A) =

	MD	PD	BD	IE	QA
Plan B	133	129	120	128	110
Plan A	133	135	160	128	154
Plan F	61	56	57	66	62
Plan H	73	80	63	78	74

S(B) =

	MD	PD	BD	IE	QA
Plan B	137	133	136	132	129
Plan A	127	133	136	124	129
Plan F	62	55	61	66	65
Plan H	74	79	67	78	77

Since the selection strategy of least sum of preference difference weighted by individual influence is applied, now we are interested in comparing C(A) and C(B) with the original C. We gain the difference of preference P(A) and P(B):

$$P(A) = |C(A) - C| = \begin{array}{l} \\ \text{Flexibility} \\ \text{Quality} \\ \text{Flow} \\ \text{Space} \\ \text{Appearance} \\ \text{Employee} \end{array} \begin{array}{c} \begin{array}{ccccc} \text{MD} & \text{PD} & \text{BD} & \text{IE} & \text{QA} \end{array} \\ \begin{bmatrix} 0.83 & 0 & 0 & 0.67 & 0 \\ 0.00 & 0 & 0 & 0.00 & 0 \\ 0.16 & 0 & 0 & 0.29 & 0 \\ 0.00 & 0 & 0 & 0.00 & 0 \\ 0.67 & 0 & 0 & 0.37 & 0 \\ 0.00 & 0 & 0 & 0.00 & 0 \end{bmatrix} \end{array}$$

$$P(B) = |C(B) - C| = \begin{array}{l} \\ \text{Flexibility} \\ \text{Quality} \\ \text{Flow} \\ \text{Space} \\ \text{Appearance} \\ \text{Employee} \end{array} \begin{array}{c} \begin{array}{ccccc} \text{MD} & \text{PD} & \text{BD} & \text{IE} & \text{QA} \end{array} \\ \begin{bmatrix} 0 & 0.03 & 4 & 0 & 4 \\ 0 & 0.02 & 0 & 0 & 2 \\ 0 & 0.10 & 0 & 0 & 1 \\ 0 & 0.59 & 0 & 0 & 0 \\ 0 & 0.48 & 3 & 0 & 1 \\ 0 & 0.02 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Therefore the sum of preference difference U(A) and U(B) are:

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

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

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

$$F = \begin{bmatrix} 7 \\ 5 \\ 2 \\ 4 \\ 2 \end{bmatrix} \begin{array}{l} \text{MD} \\ \text{PD} \\ \text{BD} \\ \text{IE} \\ \text{QA} \end{array}$$

Apply the vector F as the weight on U(A) and U(B), we get:

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

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

And the sum of $U^f(A)$ and $U^f(B)$:

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

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

According to the rule of $Min\left(\sum U^f\right)$, The IE engineer selects Plan A as the target plan, and try to negotiate or persuade all members to accept Plan A as the final decision.

Chapter 4 Conclusions

As facility layout problems are usually treated as design problems, few researches discuss about the facility layout selection problems. But in the scenario of frequent facility layout modifications, the problem is not simply a design problem. Any perfect facility layout design may lose its adequacy after frequently modifications. We discover that companies in EMS industry suffer the frequent and costly facility layout modifications. The facility layout problems in this scenario need to focus on selecting a suitable alternative among all possible alternatives. As a result, the problem becomes a selection problem in the scenario.

The actual decision making situation of facility layouts in this scenario is: First, design several alternatives in a short time, the new layout designs don't need to be perfect, but must be fast and flexible. Second, make a decision within these alternatives. Third, Execute the layout modifications as soon as possible. Under such a situation, good decisions of facility layout selections are therefore critical.

To investigate the actual decision making of facility layout selections in enterprises, the decision making is always subjective. Usually, when some facility layout alternatives are developed, the decisions are always made according to managers' experiences or preferences. Once the facility layout modifications are frequent and costly, this decision making problem turns out to be more important.

On account of the motivation to make the decision making of selecting facility layout alternatives more objective and effective, we propose a decision support model for reference in this research. With this model, alternatives are compared according to specific figures, therefore the decision making is objective. And the decision making process follows certain steps, that is, set the attributes, decide the quantitative indices and applying ranking methods, so the decision making is systematic. This decision model considers group decision scenario, and propose the potential consensus alternative for negotiations, thus achieve the goals of timesaving and overall approval. Finally, this model can especially show its value once the decision making for selecting facility layout alternatives is frequently occurred in practice.

To sum up, we propose a support model for selecting facility layout alternatives with an objective and systematic procedure in this study. This model may be a reference for further related research about the facility layout selection problems.

Appendix I

Factors or Considerations in selecting the Layout

1. EASE OF FUTURE EXPANSION (The simplicity of increasing the space employed.)

a. Tie-in with long-range potential use of the space, with the future plans for building or property development, with the basic overall allocation of space, and with the overall flow pattern(s).

b. Ability to spread out to adjacent areas-beside, above, below, to encroach on readily moved storage or service area, or to add vertical storage equipment, balconies, mezzanines.

c. Freedom from fixed or permanent building features, from divided or honeycombed areas, and from space blocked-in by physically long equipment, property lines, natural obstructions or limitations and the like.

d. Regularity of allocated space amounts in terms of readily exchangeable amounts and types of areas, modular units of layout space, multiple unit areas.

e. The amount of disruption or rearrangement of areas other than the one(s) specifically being expanded.

f. Shrinkability- ease of contracting the layout economically, to cut down the size if necessary.

2. ADAPTABILITY AND VERSATILITY (The ease of accommodating, in the layouts as planned (without rearrangement), changes (normal or emergency) in, and variety (or number) of, items like the following.)

a. Product, materials, or items

b. Quantity or volume

c. Frequency of delivery

d. Process equipment

e. Operation sequence

f. Working methods and operating time

g. Handling or storing methods

h. Utilities or auxiliaries

i. Other services

j. Type or classification of employees

k. Time-keeping or count System

l. Hours of work

m. Material dispatching procedure

n. Inspection controls

o. Rework procedures

p. Standby equipment

q. Additional space for stock

r. Alternate routes

s. Test runs, pilot lots, experimental engineering

3. FLEXIBILITY OF LAYOUT (The ease of physically rearranging the layout to accommodate changes.)

a. Mobility of machinery and equipment

b. Relative size and fixity of equipment

c. Standardization of equipment, containers, work places

d. Freedom from fixed building features or walls, unmatching floor levels, other barriers

e. Overly dense saturation of space

f. Independence or self-sufficiency of facilities (not dependent on central coordination or centralized service tie-in)

g. Ready accessibility of service lines, piping, power distribution, heating and ventilating, service holes, etc.

h. Access to the area laid out at more than one point or side

4. FLOW OR MOVEMENT EFFECTIVENESST (The effectiveness of sequenced working operations or steps-without unnecessary back-tracking, cross flow, transfers, long hauls-of materials, paper work, or people.)

a. Greatest flow intensities with minimum distances

b. Basic regularity or consistency of flow pattern(s)

c. Proximity of related areas to each other where movement of materials, people, or major paper work in involved, or where frequent, urgent or significant personal contact takes place

d. Access to, away from, and between major distances areas（like receiving, shipping, key operation

e. Flow of auxiliary or service materials: suppliers, tools, scrap or waste, and other service materials

f. Accessibility for delivery and pick-up, visitors, or employed non-company service personnel

5. MATERIALS HANDLING EFFECTIVENESS (The ease or simplicity of the handling system, equipment, and containers to move materials into, through, and out of the areas laid out.)

a. Ease of tie-in with external handling methods and equipment: rail line, docks, highway, and other accessways

b. Necessity for re-handling, extra handling, delays, awkward positioning, under physical effort, undue dependence on frequency or urgency of moves, undue amount of jury-ring or non-integrated equipment

c. Traffic congestion and interferences other than due to flow pattern

d. Balance variety of handling systems, equipment and containers

e. High utilization of handling equipment and containers

f. Simplicity of handling devices

g. Equipment integrated for multiple use

h. Dependence on M.H. equipment on maintenance, repair, replacement parts

i. Avoidance of synchronizing two or more people at same time or place

j. Ability to move completely around buildings on company property

k. Take advantage of gravity

l. Combined purposes of handling equipment for storing, pacing, sequencing, inspecting, work-holding, weighting and the like, as well as moving

6. STORAGE EFFECTIVENESS (The effectiveness of holding required stocks of materials, parts, products, service items.)

a. Inclusion of all storage-raw, in process, finished goods, supplies, tools, scrap or waste, trash and equipment or materials not in current use

b. Accessibility of items stored

c. Ease of locating or identifying items stored

d. Ease of stock and inventory control

e. Ability to make stored items available according to urgency of demand

f. Protection of material (fire, moisture, dust, dirt, heat, cold, pilferage, deterioration, spoilage.)

g. Adequacy of storage space(s)

h. Suitably close to points of delivery and use

7. SPACE UTILIZATION (The degree to which floor area and cubic space is put to use)

a. Conservation of floor space, property, or land-or most desirable portions thereof

b. Utilization of overhead space in terms of cubic density

c. Ability to share or exchange space among similar activities, and balancing of areas with seasonally complimentary space requirements

d. Effectiveness of aisle space: to serve areas adjacent to them, to lead to areas needing access, to handle traffic without wasting space or without excessive aisleways (too few, too many, too wide, too narrow, too cornered or crooked, too angular.)

e. Waste or idle space, caused by split, divided, cornered, scattered or otherwise honeycombed structures, too-close columns, too-frequent partitions or walls

f. Less desirable or out-of-way space utilized for slow, dead areas; convenient space for fast, active areas

8. EFFECTIVENESS OF SUPPORTING SERVICE INTEGRATION (The way supporting areas are arranged so as to serve the operating areas.)

a. Ability of existing (or planned) systems, procedures, and controls to work effectively with the layout, including: production planning, scheduling and control, time-keeping, material or stock issuing, work count, tool control, personnel records, receiving and shipping system

b. Ability of the layout to integrate with desired or effective pay plans, performance, cost reports, lot size, order quantities

c. Physical closeness of serving areas according to each area's need for the service (actual versus desired relationships)

d. Ability of the utilities, auxiliary service lines, and central distribution or collection system to serve the layout (Compressors, stem generators, transformers, chargers, and the like, and their accompanying pipes, ducts, wiring, etc.)

e. Service convenience of baler, salvage equipment, reclaim, incinerators, filter beds, scrap collection, and similar waste control areas or equipment

f. Ability of engineering groups, and technical advisors to support the layout effectively

9. SAFETY AND HOUSEKEEPING (The effect of the layout and its features on accidents or damage to employees and facilities, and on the general cleanliness of the area involved.)

a. Basic regularity of the aisles and work areas, and degree of freedom from equipment protruding into aisles or work areas congestion, blind corners

b. Degree to which all safety codes and regulations are satisfied

c. Risk of danger to people or equipment

d. Availability of adequate exits and clear escapeways

e. First-aid facilities and fire extinguishers nearby

f. Floors free of obstructions, spillage, and mess, and not overly congested

g. Adequate protection or segregation for dangerous or unsightly operations

h. Workers not located under or above unprotected hazards; workers not located too near moving parts, unguarded equipment, and other hazards

i. Workers able to get benefit from special safety devices or guards

j. Effectiveness of ways to clean or clear area of waste, offal, trimmings, trash

k. Ease of keeping areas clean, sanitary, snow-white, under controlled conditions

10. WORKING CONDITIONS AND EMPLOYEE SATISFACTION (The extent to which the layout contributes to making the area(s) a pleasant place to work and free from inconveniences, awkwardness, or disruptions for employees.)

a. Effect of layout on attitude, performance, or general morale of employees

b. Working conditions suitable to the type of operation

c. Suitability of the layout's arrangement and allocated space to the personnel

d. Convenience for employees-access, distances, interruptions, delays, and adequacy and convenience of parking, lockers, rest rooms, food facilities, etc.

e. Freedom from features causing workers to feel afraid, hemmed-in, embarrassed, discouraged, discriminated against

f. Noise, distractions, or undue heat, cold drafts, dirt, glare, or vibrations

g. Utilization of employee know-how and skills

h. Balanced manpower allocations

11. EASE OF SUPERVISION AND CONTROL (The ease or difficulty for supervisors and managers to direct and control the operations for which they are responsible.)

a. Ability to see the area fully and easily

b. Ability to get around the area conveniently

c. Ease of controlling quality, quantity counts, schedules, inventories in process

d. Ease of controlling waste time, lost materials, or supplies

e. Ease of moving or reassigning personnel to other work

12. APPEARANCE, PROMOTIONAL VALUE, PUBLIC OR COMMUNITY RELATIONS (The ability of the layout to afford engaging or attractive facilities, having value in promoting the company name or reputation in the community and territories served by the company.)

a. Attractiveness of external or viewable features, yards, main structure, out buildings

b. Ability to serve as show-place or reflect reliability, progressiveness or other company qualities

c. Regularity, symmetry, clean-lines, and organized appearance

d. Fit with community appearance, tradition, character

e. Effects on neighbors (benefits and irritants)

13. QUALITY OF PRODUCT OR MATERIAL (The extent to which the layout affects quality of the product, material, or their workmanship.)

a. Damage or risk to materials caused by nature of the layout or its transport facilities

b. Contamination, corrosion, spoilage, or other detriments to the product's nature or condition as caused by the layout

c. Convenience and inter-relationship of quality control activities: inspection areas Q. C. office, test facilities, control laboratories, engineering office, sample room, gauge crib, and the like

14. MAINTENANCE PROBLEMS (The extent to which the layout will benefit or hinder maintenance work, including building and machine repair as well as day-to-day service.)

a. Adequacy of facilities for maintenance and repair work

b. Sufficiency of space for access to machinery and equipment to be lubricated, checked, cleaned, adjusted, on-spot repaired, or otherwise maintained

c. Appropriate janitor and cleaner facilities

15. FIT WITH COMPANY ORGANIZATION STRUCTURE (The degree to which the layout matches or disrupts the planned or desired organization structure.)

a. Eliminate, combine, or streamline supervision, or effectiveness with which the layout helps otherwise improve the alignment of managerial personnel

b. Areas having the same supervisory responsibility are adjacent or convenient to each other

c. Staffing or manning of layout fits with job classifications and salary schedules

16. EQUIPMENT UTILIZATION (The extent to which machinery and equipment, both operating and service, is used.)

a. Degree of utilizing all equipment: operating, utility and auxiliary handling, storing, servicing or otherwise supporting

b. Necessity for duplicating equipment caused by layout versus use of common equipment and services

c. Over-capacity equipment necessitated by the layout

d. Man-machine efficiency planned into the layout

17. PLANT SECURITY AND THEFT (The ease or difficulty of safeguarding company proprietary or security-classified information, and of controlling theft or pilferage.)

a. Ease of controlling and / or monitoring access to the plant:
during working hours,
during off - shift hours

b. Ability to provide guard-controlled traffic access for all pedestrian and vehicular

c. Effective control of visitor or casual access to secure areas or information within the plant

d. Provision of adequate vaults for safe, secure storage of valuable or confidential records and documents

e. Ease of patrolling building(s) and / or grounds

f. Ease of controlling access to and dispensing of: drug supplies, tools, and expendables or easily pilfered items

18. UTILIZATION OF NATURAL CONDITIONS, BUILDING OR SURROUNDINGS (The extent to which the layout takes advantage of or capitalizes on the natural conditions of the site, physical surroundings, building structure, or neighboring areas, and the suitability of the layout to these features.)

a. Slope, topography, foundation, drainage

b. Direction of sun, prevailing wind

c. Rail line, highway, waterway, bridges, accessways, crossings

d. Building features, structure, shape, height, construction, docks, door locations elevator(s), windows, walls, columns

e. Zoning of site and restrictions of community or neighborhood

f. Fit of the area(s) laid out onto the natural site or into the existing building or area allocated

19. ABILITY TO MEET CAPACITY OR REQUIREMENTS (How well the layout actually meets the planned needs or output wanted from the installation,)

a. The right products or materials, properly meeting specifications

b. The right quantities of each variety or item in the operating time planned, without overtime or premium pay

c. The right yield in terms of projected quantities and qualities of product

20. COMPATIBILITY WITH LONG-RANGE COMPANY PLAN (The ability of the planned layout to fit with long- range growth projections and with tong-range master site plan or to total facilities development Plan(s).)

a. Degree of tie-in with long - range projections of products and/or materials, sales or operating quantities, process sequence and equipment, services, working hours and operating times

b. The ease of complete renovation, rehabilitation, modernization, or change in function

c. Ease of integration with other buildings, plants, or sites of the organization

d. Effect of the layout on the re-sale value of the property

Appendix II

Quantitative indices for Lin and Sharps' flow attribute group

(1) Clearness:

Measure 1:

$$\frac{\sum\left[(\text{open space})(\text{shape ratio})^{0.5}+(\text{semi-open space})(\text{shape ratio})^{0.5}/\left[(\text{number of columns})+1\right]^{1/3}\right]}{\text{number of separated parts}}$$

Measure 2:

1. If there is no partition/wall in the entire area (columns may still exist), then use:

$$(\text{open space})(\text{ratio})k^{1/5} \quad \text{or} \quad \frac{(\text{semi-open space})(\text{ratio } k)^{1/5}}{(\text{number of columns}+1)^{1/3}}$$

2. If there is a partition/wall, then use:

$$(\text{whole ratio } k)^{1/5}\times\frac{\sum\left[(\text{open space})(\text{shape ratio})^{0.5}+(\text{semi-open space})(\text{shape ratio})^{0.5}/\left[(\text{number of columns})+1\right]^{1/3}\right]}{\text{number of separated parts}}$$

* Open space is a space without interior columns.

* Semi-open space is a space with some interior columns.

* Ratio k = (shape ratio)(area ratio)/(perimeter ratio)

* Shape ratio is the ratio of (shortest side)/(longest side) of the smallest rectangle covering the area considered

* Area ratio is the ratio of (actual space of the area)/ (space of the covering rectangle).

* Perimeter ratio is the ratio of (actual perimeter length of the area)/ (perimeter length of the covering rectangle)

(2) Space sufficient and utilization

1. If there is no free space left, then use:

$$\left(1-\left|1-\text{target value}\right|\right)$$

2. If there is only one free space part, use:

$$\left(1-\left|1-\frac{\text{total free space}}{\text{total area}}-\text{target value}\right|\right)\left(\frac{\text{free space}}{\text{total area}}\right)^{2}(\text{shape ratio})^{1/3}$$

3. If there is more than one free space part, use:

$$\left(1-\left|1-\frac{\text{total free space}}{\text{total area}}\text{ - target value}\right|\right)(\text{whole ratio S})^{1/2}\left[\sum_{\text{free space part}}\left(\frac{\text{free space}}{\text{total area}}\right)^2(\text{shape ratio})^{1/3}\right]$$

(3) Aisle

$$\frac{(\text{mean of dept. shape ratio})}{\left(\sum_{\text{cross point}}\text{number of intersections}\right)(\text{total aisle length})/(\text{total perimeter length})}$$

or, $$\frac{(\text{mean of dept. shape ratio})}{\left(\sum_{\text{cross point}}\text{number of intersections}\right)}\times\frac{[1-(\text{st. dev. of dept. shape ratio})]}{(\text{total aisle length})/(\text{total premeter length})}$$

If the layout alternatives have different spaces, then use:

$$\frac{[1-(\text{st. dev. of dept. shape ratio})]}{\left(\sum_{\text{cross point}}\text{number of intersections}\right)}\times\frac{(\text{mean of dept. shape ratio})(\text{total area})}{(\text{total aisle length})/(\text{total perimeter length})}$$

(4) Distance and density

1. The volume of material moved through the aisles:

$$\sum(\text{travel distance})\times(\text{volume of material moved})\text{, or}$$

$$\sum(\text{travel distance})\times[1+(\text{number of floors transferred})\times(\text{weight of floor direction})]^{0.5}\times(\text{volume of material moved})$$

2. The time spent to move the material:

$$\sum[(\text{travel time between departments})+(\text{pick - up time})+(\text{put - down time})]$$

(5) Robustness of equipment capacity

1. If the capacity and capability of each sub-system are the same, use:

$$[(\text{total system capacity available})/(\text{current capacity need})]$$

2. If the capacity and capability of each sub-system is different although the capacity is the same, use:

$$[(\text{total system capacity available})/(\text{current capacity need})][\text{number of system}]^{1/2}$$

3. If the capacity and capability of each sub-system are different, use:

$$\left(\frac{\text{total system capacity available}}{\text{current capacity need}}\right)(\text{number of sub - system})^{0.5}\left[\sum_{\text{sub-system i}}(\text{capacity of sub - system i})\right]^{0.5}$$

Appendix III

(1.1) LINGO program for the model of Linear Assignment method

```
SETS:
PLANS/A,B,C,D,E,F,G,H/;
RANKINGS/1..8/;
LINKS(PLANS,RANKINGS):WEIGHT,ASSIGN;
ENDSETS
MAX=@SUM(LINKS:WEIGHT*ASSIGN);
@FOR(PLANS(I):
@SUM(RANKINGS(J):ASSIGN(I,J))<1);
@FOR(RANKINGS(J):
@SUM(PLANS(I):ASSIGN(I,J))>1);
DATA:
WEIGHT=0,0.475,0,0.05,0.15,0,0,0,
0.4,0.025,0,0.05,0.2,0.15,0,0,
0.15,0.175,0.2,0.15,0,0,0,0,
0.15,0,0.2,0.3,0.1,0.2,0,0,
0.1,0.075,0.075,0.05,0.15,0.05,0,0,
0,0.025,0.25,0.2,0,0,0,0,
0.1,0.15,0.1,0,0.15,0.05,0,0,
0.1,0.075,0.175,0.2,0,0,0,0;
ENDDATA
END
```

(1.2) LINGO result for P*

```
Rows=     17 Vars=     64 No. integer vars=      0  ( all are linear)
 Nonzeros=    179 Constraint nonz=   128(   128 are +- 1) Density=0.162
 Smallest and largest elements in abs value=   0.250000E-01    1.00000
 No. < :   8 No. =:   0 No. > :   8, Obj=MAX, GUBs <=   8
 Single cols=    0
 Optimal solution found at step:        41
 Objective value:               1.675000
```

Variable	Value	Reduced Cost
WEIGHT(A, 1)	0.0000000	0.0000000
WEIGHT(A, 2)	0.4750000	0.0000000
WEIGHT(A, 3)	0.0000000	0.0000000
WEIGHT(A, 4)	0.5000000E-01	0.0000000
WEIGHT(A, 5)	0.1500000	0.0000000
WEIGHT(A, 6)	0.0000000	0.0000000
WEIGHT(A, 7)	0.0000000	0.0000000
WEIGHT(A, 8)	0.0000000	0.0000000
WEIGHT(B, 1)	0.4000000	0.0000000
WEIGHT(B, 2)	0.2500000E-01	0.0000000
WEIGHT(B, 3)	0.0000000	0.0000000
WEIGHT(B, 4)	0.5000000E-01	0.0000000
WEIGHT(B, 5)	0.2000000	0.0000000
WEIGHT(B, 6)	0.1500000	0.0000000
WEIGHT(B, 7)	0.0000000	0.0000000
WEIGHT(B, 8)	0.0000000	0.0000000
WEIGHT(C, 1)	0.1500000	0.0000000
WEIGHT(C, 2)	0.1750000	0.0000000
WEIGHT(C, 3)	0.2000000	0.0000000
WEIGHT(C, 4)	0.1500000	0.0000000
WEIGHT(C, 5)	0.0000000	0.0000000
WEIGHT(C, 6)	0.0000000	0.0000000
WEIGHT(C, 7)	0.0000000	0.0000000
WEIGHT(C, 8)	0.0000000	0.0000000
WEIGHT(D, 1)	0.1500000	0.0000000
WEIGHT(D, 2)	0.0000000	0.0000000
WEIGHT(D, 3)	0.2000000	0.0000000
WEIGHT(D, 4)	0.3000000	0.0000000
WEIGHT(D, 5)	0.1000000	0.0000000

WEIGHT(D, 6)	0.2000000	0.0000000
WEIGHT(D, 7)	0.0000000	0.0000000
WEIGHT(D, 8)	0.0000000	0.0000000
WEIGHT(E, 1)	0.1000000	0.0000000
WEIGHT(E, 2)	0.7500000E-01	0.0000000
WEIGHT(E, 3)	0.7500000E-01	0.0000000
WEIGHT(E, 4)	0.5000000E-01	0.0000000
WEIGHT(E, 5)	0.1500000	0.0000000
WEIGHT(E, 6)	0.5000000E-01	0.0000000
WEIGHT(E, 7)	0.0000000	0.0000000
WEIGHT(E, 8)	0.0000000	0.0000000
WEIGHT(F, 1)	0.0000000	0.0000000
WEIGHT(F, 2)	0.2500000E-01	0.0000000
WEIGHT(F, 3)	0.2500000	0.0000000
WEIGHT(F, 4)	0.2000000	0.0000000
WEIGHT(F, 5)	0.0000000	0.0000000
WEIGHT(F, 6)	0.0000000	0.0000000
WEIGHT(F, 7)	0.0000000	0.0000000
WEIGHT(F, 8)	0.0000000	0.0000000
WEIGHT(G, 1)	0.1000000	0.0000000
WEIGHT(G, 2)	0.1500000	0.0000000
WEIGHT(G, 3)	0.1000000	0.0000000
WEIGHT(G, 4)	0.0000000	0.0000000
WEIGHT(G, 5)	0.1500000	0.0000000
WEIGHT(G, 6)	0.5000000E-01	0.0000000
WEIGHT(G, 7)	0.0000000	0.0000000
WEIGHT(G, 8)	0.0000000	0.0000000
WEIGHT(H, 1)	0.1000000	0.0000000
WEIGHT(H, 2)	0.7500000E-01	0.0000000
WEIGHT(H, 3)	0.1750000	0.0000000
WEIGHT(H, 4)	0.2000000	0.0000000
WEIGHT(H, 5)	0.0000000	0.0000000
WEIGHT(H, 6)	0.0000000	0.0000000
WEIGHT(H, 7)	0.0000000	0.0000000
WEIGHT(H, 8)	0.0000000	0.0000000
ASSIGN(A, 1)	0.0000000	0.4500000
ASSIGN(A, 2)	1.000000	0.0000000
ASSIGN(A, 3)	0.0000000	0.5500000
ASSIGN(A, 4)	0.0000000	0.4500000
ASSIGN(A, 5)	0.0000000	0.3000000

```
ASSIGN( A, 6)      0.0000000         0.3500000
ASSIGN( A, 7)      0.0000000         0.3000000
ASSIGN( A, 8)      0.0000000         0.3000000
ASSIGN( B, 1)       1.000000         0.0000000
ASSIGN( B, 2)      0.0000000         0.4000000
ASSIGN( B, 3)      0.0000000         0.5000000
ASSIGN( B, 4)      0.0000000         0.4000000
ASSIGN( B, 5)      0.0000000         0.2000000
ASSIGN( B, 6)      0.0000000         0.1500000
ASSIGN( B, 7)      0.0000000         0.2500000
ASSIGN( B, 8)      0.0000000         0.2500000
ASSIGN( C, 1)      0.0000000         0.0000000
ASSIGN( C, 2)      0.0000000         0.0000000
ASSIGN( C, 3)      0.0000000         0.5000000E-01
ASSIGN( C, 4)      0.0000000         0.5000000E-01
ASSIGN( C, 5)      0.0000000         0.1500000
ASSIGN( C, 6)      0.0000000         0.5000000E-01
ASSIGN( C, 7)       1.000000         0.0000000
ASSIGN( C, 8)      0.0000000         0.0000000
ASSIGN( D, 1)      0.0000000         0.1500000
ASSIGN( D, 2)      0.0000000         0.3250000
ASSIGN( D, 3)      0.0000000         0.2000000
ASSIGN( D, 4)      0.0000000         0.5000001E-01
ASSIGN( D, 5)      0.0000000         0.2000000
ASSIGN( D, 6)       1.000000         0.0000000
ASSIGN( D, 7)      0.0000000         0.1500000
ASSIGN( D, 8)      0.0000000         0.1500000
ASSIGN( E, 1)      0.0000000         0.5000000E-01
ASSIGN( E, 2)      0.0000000         0.1000000
ASSIGN( E, 3)      0.0000000         0.1750000
ASSIGN( E, 4)      0.0000000         0.1500000
ASSIGN( E, 5)       1.000000         0.0000000
ASSIGN( E, 6)      0.0000000        -0.2980232E-08
ASSIGN( E, 7)      0.0000000         0.0000000
ASSIGN( E, 8)      0.0000000         0.0000000
ASSIGN( F, 1)      0.0000000         0.1500000
ASSIGN( F, 2)      0.0000000         0.1500000
ASSIGN( F, 3)       1.000000         0.0000000
ASSIGN( F, 4)      0.0000000         0.0000000
ASSIGN( F, 5)      0.0000000         0.1500000
```

ASSIGN(F, 6)	0.0000000	0.5000000E-01
ASSIGN(F, 7)	0.0000000	0.0000000
ASSIGN(F, 8)	0.0000000	0.0000000
ASSIGN(G, 1)	0.0000000	0.5000000E-01
ASSIGN(G, 2)	0.0000000	0.2500000E-01
ASSIGN(G, 3)	0.0000000	0.1500000
ASSIGN(G, 4)	0.0000000	0.2000000
ASSIGN(G, 5)	0.0000000	0.0000000
ASSIGN(G, 6)	0.0000000	0.0000000
ASSIGN(G, 7)	0.0000000	0.0000000
ASSIGN(G, 8)	1.000000	0.0000000
ASSIGN(H, 1)	0.0000000	0.5000000E-01
ASSIGN(H, 2)	0.0000000	0.1000000
ASSIGN(H, 3)	0.0000000	0.7500000E-01
ASSIGN(H, 4)	1.000000	0.0000000
ASSIGN(H, 5)	0.0000000	0.1500000
ASSIGN(H, 6)	0.0000000	0.5000000E-01
ASSIGN(H, 7)	0.0000000	0.0000000
ASSIGN(H, 8)	0.0000000	0.0000000

Row	Slack or Surplus	Dual Price
1	1.675000	1.000000
2	0.0000000	0.5500000
3	0.0000000	0.5000000
4	0.0000000	0.2500000
5	0.0000000	0.4000000
6	0.0000000	0.2500000
7	0.0000000	0.2500000
8	0.0000000	0.2500000
9	0.0000000	0.2500000
10	0.0000000	-0.1000000
11	0.0000000	-0.7500000E-01
12	0.0000000	0.0000000
13	0.0000000	-0.5000000E-01
14	0.0000000	-0.1000000
15	0.0000000	-0.2000000
16	0.0000000	-0.2500000
17	0.0000000	-0.2500000

(2.1) LINGO program for C(A)

```
SETS:
WEIGHTS/MD1,MD2,MD3,MD4,MD5,MD6,IE1,IE2,IE3,IE4,IE5,IE6/:ADJUST,ORIGINAL;
ENDSETS
MIN=@SUM(WEIGHTS:@ABS(ADJUST-ORIGINAL));
@FOR(WEIGHTS(I):ADJUST(I)<=10);
@FOR(WEIGHTS(I):ADJUST(I)>=1);
ADJUST(1)+ADJUST(2)+ADJUST(3)+ADJUST(4)+ADJUST(5)+ADJUST(6)=20;
ADJUST(7)+ADJUST(8)+ADJUST(9)+ADJUST(10)+ADJUST(11)+ADJUST(12)=20;
(-6)*ADJUST(1)+4*ADJUST(2)+6*ADJUST(3)+(-4)*ADJUST(4)+6*ADJUST(5)+0*ADJUST(
6)>=0;
(-1)*ADJUST(1)+6*ADJUST(2)+5*ADJUST(3)+4*ADJUST(4)+7*ADJUST(5)+1*ADJUST(6)>
=0;
(-1)*ADJUST(1)+6*ADJUST(2)+5*ADJUST(3)+4*ADJUST(4)+7*ADJUST(5)+(-5)*ADJUST(
6)>=0;
(-6)*ADJUST(7)+4*ADJUST(8)+6*ADJUST(9)+(-4)*ADJUST(10)+6*ADJUST(11)+0*ADJUS
T(12)>=0;
(-1)*ADJUST(7)+6*ADJUST(8)+5*ADJUST(9)+4*ADJUST(10)+7*ADJUST(11)+1*ADJUST(1
2)>=0;
(-1)*ADJUST(7)+6*ADJUST(8)+5*ADJUST(9)+4*ADJUST(10)+7*ADJUST(11)+(-5)*ADJUS
T(12)>=0;
DATA:
ORIGINAL=5,4,2,5,2,2,6,2,4,4,2,2;
ENDDATA
END
```

(2.2) LINGO result for C(A)

```
Rows=    33 Vars=    12 No. integer vars=     0
 Nonlinear rows=     1 Nonlinear vars=    12 Nonlinear constraints=     0
 Nonzeros=   109 Constraint nonz=   70 Density=0.254
 No. < :  12 No. =:   2 No. > :  18, Obj=MIN Single cols=   0
 Optimal solution found at step:       72
 Objective value:              3.000048
```

Variable	Value	Reduced Cost
ADJUST(MD1)	4.166680	0.0000000
ADJUST(MD2)	3.999999	0.0000000
ADJUST(MD3)	2.162383	0.0000000
ADJUST(MD4)	4.999972	0.0000000
ADJUST(MD5)	2.670946	0.0000000
ADJUST(MD6)	2.000021	0.0000000
ADJUST(IE1)	5.333333	0.0000000
ADJUST(IE2)	2.000008	0.0000000
ADJUST(IE3)	4.293295	0.0000000
ADJUST(IE4)	3.999991	0.0000000
ADJUST(IE5)	2.373361	0.0000000
ADJUST(IE6)	2.000012	0.0000000
ORIGINAL(MD1)	5.000000	0.0000000
ORIGINAL(MD2)	4.000000	0.0000000
ORIGINAL(MD3)	2.000000	0.0000000
ORIGINAL(MD4)	5.000000	0.0000000
ORIGINAL(MD5)	2.000000	0.0000000
ORIGINAL(MD6)	2.000000	0.0000000
ORIGINAL(IE1)	6.000000	0.0000000
ORIGINAL(IE2)	2.000000	0.0000000
ORIGINAL(IE3)	4.000000	0.0000000
ORIGINAL(IE4)	4.000000	0.0000000
ORIGINAL(IE5)	2.000000	0.0000000
ORIGINAL(IE6)	2.000000	0.0000000

Row	Slack or Surplus	Dual Price
1	3.000048	1.000000
2	5.833320	2.000000
3	6.000001	0.9679750E-09
4	7.837617	0.0000000

5	5.000028	2.000000
6	7.329054	0.0000000
7	7.999979	0.0000000
8	4.666667	2.000000
9	7.999992	0.0000000
10	5.706705	-0.6318114E-09
11	6.000009	2.000000
12	7.626639	0.0000000
13	7.999988	0.0000000
14	3.166680	0.0000000
15	2.999999	0.0000000
16	1.162383	0.1553837E-08
17	3.999972	0.0000000
18	1.670946	0.0000000
19	1.000021	0.0000000
20	4.333333	0.0000000
21	1.000008	0.0000000
22	3.293295	0.0000000
23	2.999991	0.0000000
24	1.373361	-0.1409218E-08
25	1.000012	0.0000000
26	0.0000000	-1.000000
27	0.0000000	-1.000000
28	0.0000000	-0.1364582E-10
29	71.34176	0.0000000
30	59.34163	0.0000000
31	0.0000000	0.2865042E-09
32	62.74669	0.0000000
33	50.74662	0.0000000

(3.1) LINGO program for C(B)

```
SETS:
WEIGHTS/PD1,PD2,PD3,PD4,PD5,PD6,BD1,BD2,BD3,BD4,BD5,BD6,QA1,QA2,QA3,QA4,QA5
,QA6/:ADJUST,ORIGINAL;
ENDSETS
MIN=@SUM(WEIGHTS:@ABS(ADJUST-ORIGINAL));
@FOR(WEIGHTS(I):ADJUST(I)<=10);
@FOR(WEIGHTS(I):ADJUST(I)>=1);
ADJUST(1)+ADJUST(2)+ADJUST(3)+ADJUST(4)+ADJUST(5)+ADJUST(6)=20;
ADJUST(7)+ADJUST(8)+ADJUST(9)+ADJUST(10)+ADJUST(11)+ADJUST(12)=20;
ADJUST(13)+ADJUST(14)+ADJUST(15)+ADJUST(16)+ADJUST(17)+ADJUST(18)=20;
6*ADJUST(1)+(-4)*ADJUST(2)+(-6)*ADJUST(3)+4*ADJUST(4)+(-6)*ADJUST(5)+0*ADJU
ST(6)>=0;
5*ADJUST(1)+2*ADJUST(2)+(-1)*ADJUST(3)+8*ADJUST(4)+1*ADJUST(5)+1*ADJUST(6)>
=0;
5*ADJUST(1)+2*ADJUST(2)+(-1)*ADJUST(3)+8*ADJUST(4)+1*ADJUST(5)+(-5)*ADJUST(
6)>=0;
6*ADJUST(7)+(-4)*ADJUST(8)+(-6)*ADJUST(9)+4*ADJUST(10)+(-6)*ADJUST(11)+0*AD
JUST(12)>=0;
5*ADJUST(7)+2*ADJUST(8)+(-1)*ADJUST(9)+8*ADJUST(10)+1*ADJUST(11)+1*ADJUST(1
2)>=0;
5*ADJUST(7)+2*ADJUST(8)+(-1)*ADJUST(9)+8*ADJUST(10)+1*ADJUST(11)+(-5)*ADJUS
T(12)>=0;
6*ADJUST(13)+(-4)*ADJUST(14)+(-6)*ADJUST(15)+4*ADJUST(16)+(-6)*ADJUST(17)+0
*ADJUST(18)>=0;
5*ADJUST(13)+2*ADJUST(14)+(-1)*ADJUST(15)+8*ADJUST(16)+1*ADJUST(17)+1*ADJUS
T(18)>=0;
5*ADJUST(13)+2*ADJUST(14)+(-1)*ADJUST(15)+8*ADJUST(16)+1*ADJUST(17)+(-5)*AD
JUST(18)>=0;
DATA:
ORIGINAL=1,4,2,7,2,4,1,6,1,5,6,1,2,10,2,2,2,2;
ENDDATA
END
```

(3.2) LINGO result for C(B)

```
Rows=    49 Vars=    18 No. integer vars=     0
 Nonlinear rows=     1 Nonlinear vars=    18 Nonlinear constraints=     0
 Nonzeros=   163 Constraint nonz=  105 Density=0.175
 No. < :  18 No. =:   3 No. > :  27, Obj=MIN Single cols=   0
 Optimal solution found at step:       89
 Objective value:              16.50978
```

Variable	Value	Reduced Cost
ADJUST(PD1)	1.025558	0.0000000
ADJUST(PD2)	3.984000	0.0000000
ADJUST(PD3)	1.903345	0.0000000
ADJUST(PD4)	7.585265	0.0000000
ADJUST(PD5)	1.523056	0.0000000
ADJUST(PD6)	3.978774	0.0000000
ADJUST(BD1)	4.618763	0.0000000
ADJUST(BD2)	5.999923	0.0000000
ADJUST(BD3)	1.000000	0.0000000
ADJUST(BD4)	4.657500	0.0000000
ADJUST(BD5)	2.723814	0.0000000
ADJUST(BD6)	1.000000	0.0000000
ADJUST(QA1)	6.025306	0.0000000
ADJUST(QA2)	8.037496	0.0000000
ADJUST(QA3)	1.000000	0.0000000
ADJUST(QA4)	1.999537	0.0000000
ADJUST(QA5)	1.000000	0.0000000
ADJUST(QA6)	1.937662	0.0000000
ORIGINAL(PD1)	1.000000	0.0000000
ORIGINAL(PD2)	4.000000	0.0000000
ORIGINAL(PD3)	2.000000	0.0000000
ORIGINAL(PD4)	7.000000	0.0000000
ORIGINAL(PD5)	2.000000	0.0000000
ORIGINAL(PD6)	4.000000	0.0000000
ORIGINAL(BD1)	1.000000	0.0000000
ORIGINAL(BD2)	6.000000	0.0000000
ORIGINAL(BD3)	1.000000	0.0000000
ORIGINAL(BD4)	5.000000	0.0000000
ORIGINAL(BD5)	6.000000	0.0000000

ORIGINAL(BD6)	1.000000	0.0000000
ORIGINAL(QA1)	2.000000	0.0000000
ORIGINAL(QA2)	10.00000	0.0000000
ORIGINAL(QA3)	2.000000	0.0000000
ORIGINAL(QA4)	2.000000	0.0000000
ORIGINAL(QA5)	2.000000	0.0000000
ORIGINAL(QA6)	2.000000	0.0000000

Row	Slack or Surplus	Dual Price
1	16.50978	1.000000
2	8.974442	0.0000000
3	6.016000	0.0000000
4	8.096655	0.0000000
5	2.414735	0.0000000
6	8.476944	0.0000000
7	6.021226	0.0000000
8	5.381237	-2.000000
9	4.000077	0.0000000
10	9.000000	0.0000000
11	5.342500	0.0000000
12	7.276186	0.0000000
13	9.000000	0.0000000
14	3.974694	0.0000000
15	1.962504	-8.000000
16	9.000000	0.0000000
17	8.000463	0.0000000
18	9.000000	0.0000000
19	8.062338	0.0000000
20	0.2555825E-01	1.000000
21	2.984000	-2.000000
22	0.9033454	-3.000000
23	6.585265	0.0000000
24	0.5230562	-3.000000
25	2.978774	0.0000000
26	3.618763	0.0000000
27	4.999923	-0.6319711E-08
28	0.0000000	-2.000000
29	3.657500	0.0000000
30	1.723814	0.0000000
31	0.0000000	-2.000000

32	5.025306	0.0000000
33	7.037496	0.0000000
34	0.0000000	-10.00000
35	0.9995370	0.0000000
36	0.0000000	-10.00000
37	0.9376617	-4.000000
38	0.0000000	1.000000
39	0.0000000	1.000000
40	0.0000000	5.000000
41	0.0000000	-0.5000000
42	77.37640	0.0000000
43	53.50375	0.0000000
44	0.0000000	-0.2691510E-09
45	75.07747	0.0000000
46	69.07747	0.0000000
47	0.0000000	-1.000000
48	64.13548	0.0000000
49	52.50951	0.0000000

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