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Site Selection of Manufacturing Plants by Multiple Attributes Decision Making Methods

by

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CHAPTER 1

INTRODUCTION

Determination of a new manufacturing plant location is an important managerial decision. The problem typically involves multiple criteria and ought to be modeled as such. The problem has the following aspects: multiple attributes, incommensurable units, conflict among attributes, intangibility, and selection problem. The literature on locational decisions is huge, but there are few papers which have dealt with more than one criterion simultaneously. In the past two decades, many authors have studied the location problem involving a quantitative attribute to minimize the transportation costs. In a practical application, we need to consider several criteria simultaneously. Qualitative, as well as quantitative, factors should be considered in solving manufacturing plant location problems. However, an explicit consideration of both qualitative and quantitative attributes in developing the "optimum" solution is a difficult undertaking. Qualitative attributes are not easily measured on an interval or ratio scale. Consequently, it is difficult to combine qualitative and quantitative attributes in a quantitative approach such that a satisfactory evaluation of alternative solution is obtained.

Multiple Attribute Decision Making (MADM), a relatively new field of study, incorporates the viewpoints of both quantitative and qualitative information, and weighting schemes into the analysis. So, MADM methods are helpful in explicitly consid-ering several criteria simultaneously. The objective of this thesis is to apply a number of multiple attributes decision making methods to obtain the most reasonable solutions to manufacturing plant location problems.

In chapter two, attributes for plant location evaluation/selection are analyzed. The influence of economic impacts on the plant location is examined first. Section two follows with an investigation of the influence of some functional impacts on the plant location. The third section of this chapter includes the consideration of community attitudes. Final section evaluates the human value (quality of life) on the influence of the plant location.

Chapter three introduces seven MADM methods (Dominance method, Conjunctive method, Consensus Ranking method, TOPSIS, ELECTRE, Analytical Hierarchy Process, and Ordinal Intersection method) which are employed in the evaluation/selection of the manufacturing plant location problems.

Chapter four presents five manufacturing plant location problems which are chosen to illustrate the applications of the proposed MADM methods.

Finally, chapter five summarizes and concludes the study.

CHAPTER 2

LOCATION FACTORS

This chapter reviews the major factors required in the determination of a plant location. For convenience, these are considered under the general headings of economic impacts, functional impacts, community attitudes, and quality of life. The detailed classification will be introduced in each section.

2.1 Economic impacts

1. Capital/development cost

The initial investment in any manufacturing plant must be sufficient to enable it to compete effectively; furthermore, additional capital must be forthcoming as seasonally or cyclically needed. If a plant can not obtain required operating funds, it is forced to convert fixed assets into current assets. This causes an uneconomic plant structure and eventually leads to a dissolution. Obtaining capital is generally no problem for the large industrial corporation, whose activities are financed internally from retained earings and depreciation reserves, and externally in the national money market. Small firms have difficulty in securing capital. These firms obtain a large part of their funds outside the organized money market. The credit made available by banks and other financial institutions is short term and costly. Under these conditions the capital factor would be a secondary determinant for the large corporations but remains of major force for small firms. There are some major items comprising capital cost, as follows:

Land acquisition: The need for land goes far beyond simply requiring ground on which to put the factory. The land occupied by the physical plant is of course very important, but the plant itself often occupies a relatively small part of the land area that the firm owns. Land is also needed for such purposes as the storage of materials and finished products, the parking of cars and trucks, and internal vehicle circulation. Firms with large requirements for land will find it more easily in some places than in others. It will be particularly difficult to find in and around big cities where undeveloped land is scarce and competition from other users is strong. The cost of land varies considerably from place to place, and the geographical pattern that is adopted is often quite complex.

Site preparation, foundation, and construction: The cost may vary from place to place, and this can have an important bearing on the locational choice of a plant where construction costs form a significant element in total cost or in the initial investment. There is some evidence to show that the cost of factory construction can vary

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geographically in a fairly regular fashion. Lowest costs are found in the southern states of Alabama, North Carolina, and Virginia, while highest figures are in the major manufacturing belt (26).

Facilities: The other major item considered is the cost of the machinery and other equipments placed in the factory in order to perform the manufacturing processes. The cost and technical complexity of facilities will vary greatly between industries and between firms. In some places, machinery may be easier to obtain, repair, and replace than in others, since cities concentrating on a particular activity often have specialized machine makers to serve it.

2. Operating costs

In some location problems, capital cost varies so little among the different sites that operating costs are the most influential cost factors to determine a better site. Operating costs may include the following items: labor, transportation, taxes, utilities, and raw materials.

Labor: The influence of labor on location is determined principally by five conditions: the wage level, productivity, turnover and attitudes of the workers, labor supply, and labor laws. Regarding the wage level, North-South comparisons support the view that wages and skills are lower in the South than in the North (17). Thus, the industries which traditionally pay low wages and require many unskilled workers are most readily attracted to the South. Another important index which helps to explain not only regional wage rate differences but also wage rate differences within the same region for identical jobs, is the size of the city in which the manufacturing plant is located. A manufacturing plant located in a small town or rural area would pay lower wage rates for identical jobs than one located in a large city within the same region.

Transportation: Transportation is a vital determinant of plant location when freight cost is large relative to total cost and when it varies widely at alternative sites. This factor generally has a dispersing influence on industry, particularly when freight cost is high and the plant serves an extensive market area. There are two kinds of consideration due to the freight rate.

1. Market oriented industry - A location at or near the market indicates maximum gains when (a) the final product is more expensive to transport than the raw material, (b) the finished good is perishable, (c) the consumer demand is capricious and volatile, so that a location close to buyers will allow holding inventories to a minimum.

2. Materials oriented industries - This kind of industries generally follow a common pattern: (a) transportation costs vary more widely than other costs at alternative sites. (b) the raw material loses weight in its

conversion into the finished product.

Different transportation services have different ratios of terminal to line-haul costs. For example, truck service has lower terminal cost relative to line-haul cost than does rail service. Low terminal cost makes the truck service the lowest cost carrier over the short distance, and high terminal cost makes water service the lowest cost over the long distance. Rail service is the most economical form of transportation for intermediate distance. The actual distance at which one medium has a cost advantage over another differs according to the goods being shipped, as well as other factors.

The high cost of freight on many items has forced the relocation of plant in some instances, and establishment of branch plants in other cases. New, light-weight containers have been designed. Packaging engineers are continually working out new and improved methods of reducing costs of containers, and lowering the freight costs because of the reduced size or increased capacity of the containers thus developed.

Taxation: Wherever a plant locates, it is generally liable to some form of taxation on its operating cost. Because taxes have become a part of industry's operating cost, this item should be closely checked for the possibility of state or local taxes which might be imposed on all industry in an area, or on certain types of industries. Some communities provide land and/or buildings tax free to prospective industries for certain periods, in an effort to attract new sources of employment.

Power and Fuel: There are very few modern industries that do not use some form of powered machinery, although the amount and type of energy needed will of course vary from industry to industry according to the nature of the activity conducted and the kind of technology applied. Those industries whose processes require unusually large amounts of fuel and/or power, such as certain metallurgical and chemical industries like aluminum and copper processing and the production of fertilizers, are especially sensitive to the cost of power, and areas that can produce electricity very cheaply have attracted these types of manufacturing plants. The development of aluminum production in the Pacific Northwest and in the Tennessee Valley are examples. However, there are always likely to be some areas that have a particular attraction for some industries in virtue of local circumstances which allow power to be produced relatively cheaply.

Raw materials: All manufacturing activities require material, since an industrial process is the conversion of something into a good. Some industries, like metal smelting or cotton spinning, use a very small number of materials, whereas others, like the manufacture of motor cars, may require components from hundreds of separate suppliers. The expenditure incurred in acquiring material involves both the cost of extraction and production and the cost of transporting them to the factory. The cost of extracting a mineral or manufacturing a component will affect the locational decision only if there are significant variations of price at different locations. It appears to be increasingly the case for such variations to be reduced or eliminated, sometimes by agreements within the supplying industry, and there is also a tendency for the large corporation to extend its ownership to include major sources of material so that the price and supply are fully within its control. Thus, the cost of materials can be ignored as an influence on plant location. Because the cost of material mainly depends on transportation charges, some industries are forced to locate near the source of the materials to take advantage of lower transportation costs. The steel industry which is located near the coal it uses in such great quantities, the oil refineries near the oil fields, the furniture industries located near wood-producing areas are examples.

2.2 Functional impacts

1. Labor

Availability: Without a supply of competent workers no plant can run efficiently and competitively. For this reason proof of the availability of a qualified labor force that can be employed at a reasonable cost is often required by a manufacturing plant. An area's overall unemployment rate is frequently viewed as the key index in evaluating the labor market. Partly because of past experience, many industries intuitively believe that where unemployment is high, many people are in the job market and they will have little difficulty in attracting workers. If a substantial number of the unemployed are skilled and married full-time workers between twenty and fifty-four years old, the chance are excellent that a qualified labor force is available.

Turnover rate: The rate of labor turnover is a good index of the relationship between management and labor. A high turnover rate shows up in a high labor cost, and it is directly related to productivity. However, the employed are unmarried, part-time, female, teenage workers that tend to change jobs because these workers have high turnover rates in addition to high rates of absenteeism. Industries that employ many persons from this segment of the labor force need a larger number of available workers.

Skill level: Local concentration of an industry fosters the development of a labor force particularly productive in that industry. A rubber manufacturing center like Akron or a clothing manufacturing center like New York City comes to have an advantage over rival locations in the form of skilled and experienced labor. There is a double incentive to concentration in a few centers where demands on workmanship are most exacting and the product most individualized; such advantages reside in the superior skill of the individual workman and can be carried by him to a new location if he sees inducements to move. But the character of the local labor force as a group might be even more important. A shoe manufacturer in one of the big centers like Chicago can normally get additional or substitute help with adequate experience at a few hour's notice, whereas an isolated shoe manufacturesr in a small town cannot. In other cases such as the confectionery industry, where previous training is not essential for most of the jobs, the overall size of the local labor supply is the important factor.

Unionization: The extent to which the area's workers are involved in union activity should be analyzed carefully in plant site selection. However, labor unions are not peculiar to any part of the country. They tend to be more general in large cities than in the small towns, but are not limited to any size group of cities. Workers in small towns have fewer possibilities for other employment, should union activity result in the loss of their jobs. In large cities, with numerous job opportunities, this is less likely to be true. Nearly 50 percent of all manufacturing workers are members of unions in the United States (18). However, the degree of union involvement should not be measured simply by the proportion of the manufacturing labor force that belongs to unions; the site's history of labor negotiations and contract agreements is more important. Manufacturing in the South is dominated by numerous labor-intensive nonunion small scale plants that tend to locate in small towns and rural areas. Urban services are not important for these kinds of industries, so they are attracted to small settlements that provide lower cost land and labor. In the manufacturing belt of the Northeast, manufacturing is highly diversified, highly unionized, and a metropolitan area phenomenon. These situations can be explained by the nature of industries in the Northeast - capital intensive, and requiring specialized labor, business, financial, legal, repair, transportation, communication, public and other services that are not easily offered in small towns.

Laws: State and local laws should be investigated by a manufacturer when considering various locations. Labor laws, workmen's compensation insurance laws, and unemployment regulations vary widely from one location to another. Although much of the current labor legistration is regional in scope, some laws are purely local or state-wide in nature. Some of the aspects of industrial operations regulated by law are hours of work, minimum ages, minimum wages, workmen's compensation, and working conditions for women employees. For example, the state of New Jersey has stringent restrictions on the employment of women after midnight (17). Employment Practice Acts should be studied along with the rulings of the Interstate Commerce Commission, which may penalize certain types of industries in some areas.

The overall influence of labor force factor on plant location is thus difficult to evaluate. Increasing mechanization, automation, and the substitution of capital for labor may reduce the importance of labor in the modern industrial nations. But significant region advantages with respect to labor cost, quantity, and quality still exist. The increasing sophistication of industrial processes reduces the need for unskilled labor in many industries, but the workers with special technique skills can give some sites big labor advantages. On the world level, there are still many areas where the low cost of labor is the main competitive industrial advantage, particularly in the developing countries of Africa and Asia.

2. Fuel and power

There are very few modern industries that do not use some form of powered machinery, although the amount and type of energy needed will vary from industry to industry and from plant to plant according to the nature of the activities conducted and the kind of technology applied.

Availability: Practically every industry requires fuel and power. The first consideration is the adequacy of the fuel and/or power supply for all possible requirements. For those industries which require large amounts of fuel and/or power, the decision makers would prefer plant locations near the sources of fuel and power. Originally water power was the source of the power for many processes, and plants were located where running water was conveniently available. Later, water power gave away to electricity power, and plants moved near to sources of electricity.

Reliability: The second consideration for fuel and power is the reliability of the service. Interruptions of production due to failure of power or fuel service are costly and should be guarded against. A manufacturing plant can get the best insurance of the reliable service if the plant can obtain the fuel and/or power from more than one source and from more than one route.

3. Transportation

The movement of materials can consume a very high percentage of the operating cost. There are many ways in which goods and materials can be moved from one place to another. In order to select the proper transportation service, the shipper should consider the following:

(1) The relative cost for the various service

(2) The urgency of the shipment

(3) The demand for special services, e.g. refrigeration

Truck: The extensive construction of improved highways throughout the country and the progress in the design of the motor carriers have made the truck an important factor in transpotation. The truck is at a substantial advantage in that less careful packing of goods is required. In addition to this are convenience of loading and discharge, time ecconomy, and flexibility arising from the fact that plant owned trucks may be started on their way at any hour of the day or night. Whenever a product is separated into semifinished components which are made at different plants, truck service is considered as a possible economy.

Water: Oldest among the modern transportation services is the water shipping. It is slow relative to rail service, but it is cheap and can handle much more merchandise. For example, cars manufactured in Detroit can be landed at Buffalo or Cleveland by boat at very low rates via the Great Lakes. Water transportation is well standardized in its operations and limited in its accessibility to markets and sources of materials.

Rail: Ton-mile efficiency has risen notably, as well as the speed of service and the facility of handling at terminals. Package-car service has been introduced, resulting in immeasurable benefit to the concern making frequent shipments in small quantities. The improved service, including the establishment of joint rail and water service, truck and rail service over a widened area, will be more beneficial to manufacturing. For example, at a number of sea and lake ports, the combination of rail service with steamship wharves is equipped to handle a variety of goods and materials with the utmost speed and economy.

Air: Air service is designed to handle merchandise with speed, for instance, perishable goods.

2.3 Community attitude

The attitude of a community toward the establishment of a new manufacturing plant is highly important. Burdensome regulations and high taxes on industrial property are indicative of an unfavorable community attitude. Tax exemption, cash bonuses, free land or rent and the existence of industrial foundations or factory funds are sometimes indicative of a favorable attitude. In many cases, special local favors have contributed materially to success. Of course, the reliability of such gestures should be checked before any agreement is made to locate the plant in a particular community. The first thing a site selection team must do is to evaluate the disadvantage and advantage of the community as the location of a plant. The team's task includes finding out the community's attractive features and also recognizing the unattractive features.

Most cities and towns, regardless of size, have either a Chamber of Commerce, a board of trade, an industrial bureau, or at least an industrial committee. They are the show windows; the attitude expressed is not always the true attitude of the community. This is one of the reasons why more and more manufacturing concerns are making their location investigations secretly.

For many years cities and towns, particularly those of small and medium size, have offered special inducements to attract industries such as the cash bonus, tax exemption, free land or the free use of vacant buildings, subscription to stock or bond issues, and general financial assistance through the industrial foundation.

For years the cash bonus was the most common way provided by a community to attract industry. The community would furnish the money if the manufacturer would build a plant.

Tax exemption is one of the inducements frequently provided to industries. Exemption nearly always applied to local taxes only, or to local and county taxes at most; but these generally constitute the major burden on property, for some plant location cases, this concession may be of considerable importance.

The offer of free land or the free use of vacant buildings has become quite common for communities or some other civic organization seeking to attract industry. Frequently, a land owner will get benefit from the sale of house lots or store sites nearby because a factory means a demand for homes of plant employees.

It is becoming more and more common for communities to offer subscriptions to preferred stock or bond issues at par as inducements to a manufacturer. The manufacturer issues preferred stock against his assets, agreeing to pay interest on them at a certain rate. This kind of assistance to the manufacturer seems more businesslike than the old type of bonus giving.

Although the inducements mentioned above are quite common, most manufacturers often prefer to pay their own way and make a reasonable profit. The Chamber of Commerce or a similar group may be sounded out regarding the general attitude of the community toward a new industry.

2.4 Quality of life.

When a new manufacturing plant fails to achieve projected profit and production level, the reason can frequently be found not in the investment decisions, but in management's failures to give proper consideration to quality of life factors in site selection. With appropriate attention to both economic and human values, an effective plant can be located in a community which provides opportunities for a satisfying life style for the assigned management team as well as for the plant employee recruited locally. There are four essential quality of life factors (socioculture, health, education, and residential) which must be considered in plant location problems.

1. Socioculture

This factor is particularly crucial when the plant in a small community or a rural area and the management team is transferred from one or more metropolitan plants. No wife or child can be expected to want to alter dramatically their tastes and preferrences just because the husband and father is moved to a new position with a different home environment. If the new environment can provide the basic satisfaction to every member of the family, the new community offers sociocultural function and avoids a dramatic change in living habits. However, the following items contribute to the basic satisfaction of sociocultural elements:

1. Good restaurants are important.

2. There should be theaters showing movies of interest to all members of family.

3. Major television network should be available (including educational and public service broadcasting).

4. Shopping for basic necessities should not be a problem (should have national chain supermarkets where the prices are reasonable and selection is not limited).

5. The community should have a library with business reference materials as well as general reading materials.

6. There should have organized recreation programs and facilities.

7. One should not need to drive too far to watch college or professional sports; go to a museum, see a play, watch a ballet, hear a symphony, visit a zoo, or just walk through a public garden.

8. Transportation is important, especially accessibility to an airport. If one must drive two or three hours to a small regional airport where connections to major cities are few, in such communities, it may take almost an entire day just to meet relatives and friends who wish to visit the family.

2. Health care

A good community should have physicians who provide ambulant and clinic care, and also have a pediatrician. Small communities need not have a hospital where surgery is performed. A hospital should be located no more than a thirty minute drive from the community. For an emergency surgical care, a thirty minute wait is usually acceptable. A hospital also needs registered nurses, licensed practical nurses and nurse's aids as well as physicians to provide health care. Skilled technicians must also be available to provide radiology and pathology services. In addition, resident anesthesiologists are also required to perform a surgery.

The ages of the local physicians is another important factor. The future of community health care is in jeopardy if all the physicians in the community are in their sixties. Small communities have great difficulty attracting young physicians, and the maldistribution of the medical professionals is a growing national problem. The services and facilities of any hospital can be determined from hospital magazines. The local medical directory is a public document and lists the training, residency, board specialty certification and age of all local physicians.

3. Education

The educational system of any community considered as a plant location should be studied carefully. For example, in one southern plant community, both the elementary and secondary schools are badly overcroweded and half of the elementary classes are held in makeshift metal trailers with little or no ventilation. The children often complain of unbearable heat and classes are cancelled. The education of children is of importance to men and women, and it is a major concern for the American management family. If a child attended a school where the quality of education is considered outstanding, the new school expected will be different from the expectations of a family whose child transfers from a school that is considered average. A school system can be evaluated by considering the following factors:

1. Per capita expense for education
2. Student to teacher ratio
3. Spending per student
4. Students per room
5. Teacher pay scale
6. The library budget for both new and replacement books
7. Special programs such as music and art, intramural athletic program, and the condition of the facilities.

4. Housing

Buying or building a home is one of the most important actions when a family is moving into a new community. Residential patterns may create some problems. Often the company will buy a tract of attractive residential land and encourage the managers to build their homes side by side. Because so much of a manager's time and interest is occupied by his work, each manager needs a private life with different concerns, different values, and different personal ties and friendships. Very often, residential arrangements in small towns make social outreach difficult, so, the company must recognize the problems in buying residential land for its personnel, and managers should receive counsel regarding the impact which residential patterns can have on their social relationships.

Many of the human problems in plant location can be avoided through attention to the following guidelines:

1. The executive manager should recognize the importance of quality of life factors in plant location, and senior executives should be involved in the location decision as well as in the investment decision.

2. A personnel specialist should be on the site selection committee. This specialist should make an in-depth study of each prospective site community and make detailed reports on the four quality of life factors.

3. After the plant site is selected, the company should sponsor a visit to the community and a detailed report for the people who have being considered for assignment to the new plant.

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CHAPTER 3

BASIC CONCEPTS AND METHODOLOGIES OF MADM PROBLEM

3.1 Basic concepts

An application of multiple attribute decision making (MADM) methods to the plant location problem is to select a manufacturing plant site from a set of candidates based on a set of attributes (factors). The problem can be quantified by a decision matrix D:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \cdot \\ \cdot \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} X_1 & X_2 & \cdots\cdots & X_n \end{array} \\ \left[\begin{array}{cccc} X_{11} & X_{12} & \cdots\cdots & X_{1n} \\ X_{21} & X_{22} & \cdots\cdots & X_{2n} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ X_{m1} & X_{m2} & \cdots\cdots & X_{mn} \end{array} \right] \end{array}$$

Let m be the number of alternatives (A_i, $i=1,2,.....,m$), which are evaluated according to n attributes (X_j , $j=1,2,.....,n$). A decision matrix is a (m x n) matrix whose elements X_{ij} indicate the evaluation of A_i on attribute X_j . The plant location problem has the following characteristics:

<u>Multiple attributes</u>: A decision maker must generate relevant attributs for the problem setting. In the plant

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location case, transportation cost, labor and wages, utilities, laws and taxation, ... etc. are the multiple attributes to be considered in choosing a preferable site.

Incommensurable units: We are dealing with incommensurable quantites in a manufacturing plant location problem. Some of attributes related to location problem are quantitative. The unit of one attribute may be dollars (e.g., operating cost) and those of another may be percentage, points, ...etc.; while many other attributes (e.g., higher productivity, better community relations) are mainly qualitative.

Conflict among attributes: The multiple attributes usually conflict with each other. The decision makers want to optimize each attribute, but it is rarely possible to find a plant location which does so. For instance, the location chosen may be an urban area which will make the land acquisition cost higher, but increase the labor availability and the function of transportation system.

Intangibility: Some attributes might reflect psychological aspects such as the esthetic considerations of the environment condition of a plant location. The evaluation of such attributes involves delicate problems of psychological scaling. To ignore such attributes might seriously distort an analysis.

For the qualitative and intangibility attributes, the bipolar scale is commonly used to convert a qualitative attribute into an interval scale. It should be noted that a numerical assignment value is rather subjective. The bipolar scale is shown on Fig (3.1).

Selection problem: The nature of the MADM problem is that there is a finite number of predetermined alternatives which have associated with them a level of the achievement of the attributes. The final decision is based on selecting the best one among finite alternatives.

10	perfect
9	ideal
8	excellent
7	very good
6	good
5	fair
4	average
3	poor
2	unsatisfactory
1	unacceptable

Fig. 3.1 Assignment of values on an interval scale

3.2 Dominance method

The Dominance method (6) does not need the decision maker's (DM's) preference information nor any assumption or any transformation of attributes. An alternative is dominated if there is another alternative which excels it in one or more attributes and equal it in the remainder.

We say that alternative $A_i = (X_{i1}, X_{i2}, \ldots\ldots, X_{in})$ dominates $A_k = (X_{k1}, X_{k2}, \ldots, X_{kn})$ whenever

(a) $X_{ij} \geqslant X_{kj}$, for all j

(b) $X_{ij} > X_{kj}$, for some j

The number of alternatives can be reduced by eliminating the dominated ones. A set of nondominated solution is obtained through the following dominance procedures

(1) compare the first two alternatives and if one is dominated by the other, discard the dominated one.

(2) compare the undiscarded alternatives with the third alternative and eliminate any dominated alternative. Then introduce the fourth alternative and so on.

It is helpful to use the Dominance method to eliminate the dominated alternatives when the number of attributes is small and the number of alternatives is large.

3.3 Conjunctive method (10) or (Satisficing method) (25)

The Conjunctive method needs a statement of the level which will be considered an acceptable achievement score for each attribute. Any attribute value of an alternative less than the predetermined score will be eliminated. We define A_i as an acceptable alternative only if

$$X_{ij} > X_j^o , \quad j=1,2,....,n$$

where X_j^o is the minimum level of attribute X_j. Usually, the conjunctive method is not used for selection of the best alternative but rather for separating them into acceptable and not acceptable categories. Consider a set of n equally weighted attributes. Let

r = the proportion of alternatives which are rejected

p_c = the probability that a randomly chosen alternative scores above the conjunctive cutting level.

Then

$$p_c = (1-r)^{\frac{1}{n}} \qquad (3.1)$$

For example, suppose that a decision maker evaluates plant locations on each of four attributes - economic impacts, functional impacts, community attitudes, and quality of life. Assume that the decision maker wants to eliminate five-sixths of these alternatives. Now we have

$n=4, \; r=5/6$

$$p_c = (1-5/6)^{\frac{1}{4}} = 0.64$$

Hence, the decision maker must set a minimum value for each attribute such that 64% of plant locations will place above these scores.

3.4 Consensus Ranking Method (8)

In multiple attribute decision making, the analyst must obtain information concerning the importance of each of the attributes from the decision maker. There are two types of information which may be supplied - cardinal and ordinal. Cardinal ranking arises in those situations where an individual is able not only to express a preference of one attribute over another, but the degree of preference as well. For instance, the decision maker may state that attribute 1 is three times as important as attribute 2. Ordinal rankings do not express a degree of preference. Ordinal information pertaining to the attributes is much less precisce. For example, the decision maker may state that attribute 1 is more important than attribute 2, but no information regarding the relative degrees of importance would be supplied. It was assumed that each of the decision makers could specify a priority vector denoting the ordinal preferability of a set of attributes. It was assumed that each decision maker's ranking is considered equal in importance to the rankings of any other member. The problem is to determine a consensus ranking that best agrees with all the decision makers' rankings. Cook and Seiford (8) represent a ranking set of m alternatives by a vector A = $(a_1, a_2, \ldots, a_m)$ where a_i is the rank of priority of the alternative (or the average in the case of ties). Thus if alternative 2 is ranked first, alternative 1 second, alternative 4 third, and alternative 3 last, then

$$A = (2,1,4,3) \quad ,$$

whereas

$$B = (1,4,2.5,2.5)$$

would represent the ranking in which alternative 1 is first, alternative 2 fourth, and alternative 3 and 4 are tied. The problem consists of determining the best consensus ranking for a situation in which n attributes have given ordinal ranking $(A^j)_{j=1}^n$ of m plant location alternatives, where

$$A^j = (a_1^j, a_2^j, \ldots, a_m^j)$$

Cook and Seiford show that the consensus ranking C which minimizes the total absolute distance matrix

$$D = \sum_{j=1}^{n} d(A^j, C) = \sum_{i=1}^{m}\sum_{j=1}^{n} | a_i^j - c_i | \qquad (3.2)$$

where D is a m x n (m = number of alternatives) nonnegative square matrix, and

a_i^j : rank given to alternative i by attribute j

c_i : possible rank $(i = 1,2,....,m)$

The following axioms are satisfied by the matrix D. Let $d(A,B)$ represent the distance between the ranking A and B.

Axiom 1 : $d(A,B) \geq 0$ with equality if and only if $A = B$

Axiom 2 : $d(A,B) = d(B,A)$

Axiom 3 : $d(A,E) \leq d(A,B) + d(B,E)$ with equality if and only ranking B is between A and E

Axiom 4 : If A' results from A by a permutation of the attributes and B' results from B by the same permutation, then

$$d(A',B') = d(A,B)$$

Axiom 5 : If A and B are two rankings of n attributes and A* ,B* are the rankings which result from A and B by listing the same (n+1)st attribute last then

$$d(A^*,B^*) = d(A,B)$$

Furthermore, the unique d which satisfies these axioms is given by

$$d(A,B) = \sum_i | a_i - b_i | \qquad (3.3)$$

The distance function puresented above can now be used to determine a consensus ranking. The most expeditious manner of obtaining consensus ranking is to solve the following assignment problem:

$$\min \sum_{i=1}^{m} \sum_{k=1}^{n} d_{ik} X_{ik}$$

$$\text{s.t.} \qquad \sum_{i=1}^{m} X_{ik} = 1 , \quad \text{for all } k$$

$$\sum_{k=1}^{m} X_{ik} = 1 , \quad \text{for all } i$$

$$X_{ik} \geq 0 \quad \text{for all } i,k$$

here

$$d_{ik} = \sum_{j=1}^{n} | a_i^j - k |$$

and the decision variables X are defined such that

$$X_{ik} = \begin{cases} 1 , & \text{if } c = k \\ 0 , & \text{otherwise} \end{cases}$$

If we consider atributes with different weights, the modified distance measurement can be expressed as

$$d_{ik} = \sum_{j=1}^{n} W_j | a_i^j - k |, \quad k=1,2,...,m$$

$$\sum_{j=1}^{n} W_j = 1$$

Where W_j is the weight assigned to the jth attribute. The difficulty in the tied ranking can be treated easily by using the weights (W_j, $j=1,2,...,n$). For example, three alternatives, A_1, A_2, and A_3 are tied in the jth attributewise ranking as

rank	X_j (W_j)
1st	A_1, A_2, A_3
2nd	
3rd	
4th	A_4

It can be equalized by creating two more attributes with 1/3 of the original weight value such as

rank	X_{j1} ($W_j/3$)	X_{j2} ($W_j/3$)	X_{j3} ($W_j/3$)
1st	A_1	A_3	A_2
2nd	A_2	A_1	A_3
3rd	A_3	A_2	A_1
4th	A_4	A_4	A_4

3.5 TOPSIS method

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was developed by Hwang and Yoon (14). This method is based on the concept that the chosen alternative should have the shortest distance from the ideal solution and the farthest from the negative-ideal solution. The method will be presented in the following steps:

<u>Step 1. Construct the normalized decision matrix</u>: The vector normalization procedure is employed in this method to transform the different attribute dimensions into a comparable scale, which means a dimensionless unit. This procedure defines that each attribute vector of the decision matrix is divided by its norm, so that each normalized value r_{ij} of the normalized decision matrix R can be calculated as

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad (3.4)$$

<u>Step 2. Construct the weighted normalized decision matrix</u>: This matrix can be obtained by multiplying the individual element r_{ij} by its associated weight W_j. The matrix $\underline{V}$ is equal to

$$\underline{V} = \underline{R}\ \underline{W} \qquad (3.5)$$

where W is a diagonal matrix of order n, and

$$\sum_{j=1}^{n} W_j = 1$$

<u>Step 3. Determine ideal and negative-ideal solutions</u>: Let the ideal alternative A* and the negative-ideal alternative A⁻ be defined as:

$$A^* = \left\{ \left(\max_i V_{ij} \mid j \in J \right), \left(\min_i V_{ij} \mid j \in J' \right) \ i=1,2,\ldots,m \right\}$$

$$= \left(V_1^*, V_2^*, \ldots\ldots, V_m^* \right)$$

$$A^- = \left\{ \left(\min_i V_{ij} \mid j \in J \right), \left(\max_i V_{ij} \mid j \in J' \right) \ i=1,2,\ldots,m \right\}$$

$$= \left(V_1^-, V_2^-, \ldots\ldots, V_m^- \right)$$

where

J is $\{ j=1,2,\ldots,n \mid j$ associated with benefit attribute$\}$

J' is $\{ j=1,2,\ldots,n \mid j$ associated with cost attribute $\}$

<u>Step 4. Calculate the separation measure</u>: The separation of each alternative from the ideal alternative can be measured by the n-dimensional Euclidean distance. Then the separation from the ideal alternative is given by

$$S_{i*} = \sqrt{\sum_{i=1}^{m} (V_{ij} - V_j^*)^2} \quad , \quad i=1,2,...,m \qquad (3.6)$$

Similarly, the separation from the negative-ideal is given by

$$S_{i-} = \sqrt{\sum_{i=1}^{m} (V_{ij} - V_j^-)^2} \quad , \quad i=1,2,...,m \qquad (3.7)$$

Step 5. Calculate the relative closeness to the ideal solution: The relative closeness of A_i with respect to A^* is defined as

$$C_{i*} = S_{i-} / (S_{i*} + S_{i-}) \ , \ 0 < C_{i*} < 1 \ , \ i=1,2,..,m \qquad (3.8)$$

It is clear that an alternative A_i is closer to A^* as C_{i*} approaches to 1.

Step 6. Rank the preference order: A set of preference order can be obtained according to the descending order of C_{i*}.

3.6 ELECTRE method

The ELECTRE method (Elimination et Choice Translating Reality) was originally developed in France by Benayoun et al. (2). This method was subsequently applied in various types of research. The ELECTRE method is based on a pairwise comparison of alternatives to examine both the degree of concordance among weights and the discordance differences among weight project outcomes. The concept of an outranking relationship of $A_p \rightarrow A_q$ says that even though these two alternatives do not dominate each other, the DM accepts the risk of regarding A_p as almost surly better than A_q. The first and second steps of ELECTRE are the same as those of TOPSIS. The remaining steps are presented as follows:

Step 3. Determine the concordance and discordance sets: The concordance set c_{pq} of A_p and A_q is composed of all attributes for which A_p is preferred to A_q, or A_p is equal to A_q. This set is defined as:

$$c_{pq} = (j \mid X_{pj} \geqslant X_{qj}) \qquad (3.9)$$

The complementary set is called the discordance set D and can be represented as:

$$d_{pq} = (j \mid X_{pj} < X_{qj}) \qquad (3.10)$$

Step 4. Calculate the concordance matrix: It is obvious that C_{pq} will contain more elements when A_p dominates A_q with respect to more attributes. The relative value of the concordance set is measured by means of the concordance index. This index is equal to the sum of weights for those attributes which fall into the concordance set, divided by the sum of all weights. Therefore, the concordance index c_{pq} between A_p and A_q is defined as:

$$c_{pq} = \sum_{j \in C_{pq}} W_j \Big/ \sum_{j=1}^{n} W_j \qquad (3.11)$$

Step 5. Calculate the discordance matrix: The discordance index measures the relative discrepancy between the weighted outcomes of two alternatives. The discordance index may be defined as:

$$d_{pq} = \frac{\max_{j \in D_{pq}} | V_{pj} - V_{qj} |}{\max_{j \in J} | V_{pj} - V_{qj} |} \qquad (3.12)$$

Step 6. Determine the concordance dominance matrix: By defining a threshold value for the concordance indices (in general, the average value of all concordance indices), one may state that A_p will only have a chance of being preferred to A_q if the associated index c_{pq} exceeds the threshold value $\bar{c}$; that is to say, if

$$c_{pq} \geq \bar{c}$$

In this case, $\bar{c}$ can be defined as:

$$\bar{c} = \sum_{\substack{p=1 \\ p \neq q}}^{m} \sum_{\substack{q=1 \\ q \neq p}}^{m} c_{pq} \;/\; m\,(m-1) \qquad (3.13)$$

Next, a boolean matrix F can be constructed. The elements f_{pq} of matrix F can be defined as

$$f_{pq} = 1, \text{ if } c_{pq} \geq \bar{c}$$
$$(3.14)$$
$$f_{pq} = 0, \text{ if } c_{pq} < \bar{c}$$

Matrix F is called the concordance dominance matrix; each element 1 indicates a dominance of one alternative by another in the concordance relationship.

<u>Step 7. Determine the discordance dominance matrix</u>: A_p is more worthwhile than A_q if the discordance index d_{pq} is lower. By defining a threshold value $\bar{d}$, A_p can be assumed to receive a higher priority than A_q if

$$d_{pq} \leq \bar{d}$$

The threshold value $\bar{d}$ can be calculated as

$$\bar{d} = \sum_{\substack{p=1 \\ p \neq q}}^{m} \sum_{\substack{q=1 \\ q \neq p}}^{m} d_{pq} \;/\; m\;(m-1) \qquad (3.15)$$

The elements g_{pq} of the discordance matrix G are determined

$$g_{pq} = 1, \quad \text{if } d_{pq} \leqslant \bar{d}$$

$$(3.16)$$

$$g_{pq} = 0, \quad \text{if } d_{pq} > \bar{d}$$

The interpretation of G is analogous to that of F.

<u>Step 8. Determine the aggregate dominance matrix</u>: The aggregate dominance matrix E can be directly calculated as the intersection of the concordance dominance matrix F and the discordance matrix G.

The elements e_{pq} of E satisfy the following conditions:

$$e_{pq} = 1, \quad \text{if} \quad f_{pq} = 1 \text{ and } g_{pq} = 1$$

$$(3.17)$$

$$e_{pq} = 0. \quad \text{otherwise}$$

<u>Step 9. Rank the preference order</u>: If $e_{pq} = 1$, then A_p is preferred to A_q for both the concordance and discordance criteria. The outranking relationship can be illustrated by graphical representation and gives the partial-preference ordering of the alternatives.

3.7 Analytical Hierarchy Process (AHP) (21) (22)

A hierarchy is an abstraction of the structure of a system to study the functional interactions of its components and their impacts on the whole system. This structure could have several related levels, all of which essentially descend from an overall objective down to sub-objectives, down further to factors which affect these sub-objectives. The Analytical Hierarchy Process approach will be described as the following procedure:

<u>Step 1. Decompose a complex system into a hierarchy</u>

<u>Step 2. Measurement and judgment process</u>: Let $C_1, C_2, \ldots, C_n$ be the set of activities. The quantified judgments on pairs of activities C_i, C_j are represented by an $(n \times n)$ matrix

$$A = (a_{ij}), \quad (i,j = 1,2,\ldots,n)$$

$$= \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots\cdots\cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots\cdots\cdots & w_2/w_n \\ . & . & & . \\ . & . & & . \\ . & . & & . \\ w_n/w_1 & w_n/w_2 & \cdots\cdots\cdots & w_n/w_n \end{bmatrix}$$

The elements a are defined by the following rules.

Rule 1. If $a_{ij} = k$, then $a_{ji} = 1/k$, $k \neq 0$

Rule 2. If C_i is judged to be of equal relative importance with C_j , then $a_{ij} = 1$, $a_{ji} = 1$; in particular, $a_{ii} = 1$ for all i.

For determining the priority scale (a_{ij}), Satty (22) gives an intensity scale of imporance for activities shown in Table (3.1).

For example, if attribute 1 is absolutely more important than attribute 2, insert 9 on the a_{12} position.

<u>Step 3. Calculate the eigenvalues</u>: Eigenvector method

Since $a_{ij} = 1/a_{ji}$, the matrix A is reciprocal and has all positive elements a_{ij} with the property

$$a_{ij} = a_{ik} / a_{jk} \qquad (3.18)$$

Multiplying A by $\underline{W} = (W_1 , W_2 , \ldots , W_n)^T$, we obtain

$$A \underline{W} = n \underline{W}$$

or

$$(A - n I) \underline{W} = 0 \qquad (3.19)$$

Due to the consistency property of equation (3.18), the system of homogeneous linear equations, eq (3.19) has only trivial solutions. Eq (3.19) expresses the fact that $\underline{W}$ is an eigenvector of A with eigenvalue n. In a practical problem, the a_{ij} are not based on exact measurements, but on subjective judgements. Thus, the a_{ij} will deviate from the real ratios w_i/w_j , and therefore eq (3.19) will no longer hold. We find that if A is consistent, and the diagonal of a matrix A consists of ones (a_{ii} = 1), then small variations of the a_{ij} keep the largest eigenvalue, λ_{max}, close to n, and the remaining eigenvalues close to zero. If we define A' as the decision maker's estimate of A, and W' is corresponds to A', then

$$A' \underline{W}' = \lambda_{max} \underline{W}' \qquad (3.20)$$

The priority vector $\underline{W}'$ can be obtained by solving simultaneously the linear equation (3.20), and the condition

$$\sum_{i=1}^{n} W_i = 1$$

<u>Step 4. Hierarchical composition</u>: The priority of an element in a level is the sum of its priorities in each of the subsets to which it belongs. Let B be the priority matrix of the kth level, (k=1,2,...,h). Then the composite priority vector is given by

$$W = B_h \; B_{h-1} \cdots \; B_1 \qquad (3.21)$$

If level 1 has a single element, then as usual, B_1 is just a scaler; if more, a vector.

Table 3.1 The scale and its description

Intensity of importance	Definition	Explanation
1	Equal importance	Two criteria contribute equally to the objective
3	Weak importance of one over another	Experience and judgement slightly favor one criterion over another
5	Strong importance	Experience and judgement strongly favor one criterion over another
7	Demonstrated importance	A criterion is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one criterion over another is of the highest possible order of affirmation
2,4,6,8	Intermidiate values between the two adjacent judgements	When compromise is needed

3.8 Ordinal Intersection Method (8)

The method developed by Cook and Seiford is used to choose a set of sites. Once attributewise rankings for each attribute have been provided and the budget B is known, the fundable and non-fundable subsets are determined. Suppose that for attribute 1 the ranking of eight sites is

$$R_1 = (1,4,2,6,8,7,5,3)$$

If the budget is only large enough to permit the funding of the first five sites, then the fundable set f_1 is

$$f_1 = (1,4,2,6,8)$$

The non-fundable set $\bar{f}_1$ is

$$\bar{f}_1 = (7,5,3)$$

The ordinal intersection method would proceed as follows:

<u>Step 1. Take the intersection of all n fundable sets</u>:

$$\bigcap_{i=1}^{n} f_i \qquad (3.22)$$

Call this set g_1, it is the subset of sites (which may be an empty set) which is contained in all fundable sets f_i. If g_1 contains enough sites to absorb the entire budget, we stop. If not, we go to

Step 2. Select some set of n-1 of the f (say, $f_1, f_2, \ldots, f_{n-1}$) and take their intersection

$$\bigcap_{i=1}^{n-1} f_i$$

Call this new subset g_2 . If the set $g = g_1 \cup g_2$ absorbs the budget, then stop. Otherwise, select another subset of n-1 of the f_i (say $f_1, f_2, \ldots, f_{n-2}, f_n$) and take their intersection (g_3). If the set $g = g_1 \cup g_2 \cup g_3$ absorbs the budget, stop; othewise proceed in the fashion described above.

Basically, this process attempts to select those sites which received high priority on as many attributes as possible. If the attributes are ranked ordinally only, the minimum sum of ranks could be used as a selection criterion. For example, consider the cases of four attributes, where the ordinal ranking of the four attributes is (2,4,3,1). If sets of three attributes are to be selected, the first choice would be attributes (X_1, X_3, X_4) whose sum of ranks is 1+2+3=6. The next choice would be (X_1, X_2, X_4) whose sum of ranks is 7. If g from all sets of n-1 attributes does not absorb the budget, then n-2 attributes will be examined. The process will continue until the budget is exhausted. If the decision maker has assignd cardinal weights W_j to the attributes, then in determining g_2 , subset of f_i should be chosen for which the corresponding sum of weights is maximun. When there are more than one decision makers, let R_i , i=1,2,....,m to be a set of rankings for the various sites by the ith decision maker, associated with weights which are based on his working experience with the plant location projects. Dealing with this kind of problem, the decision maker can use the consensus ranking method to solve it with respect to the decision matrix of each decision maker.

m sets of ranking order of a site selection problem can be obtained after finishing the process bove. Finally, the ordinal intersection method is employed to exhaust the total budget.

CHAPTER 4

APPLICATIONS OF MADM METHODS TO PLANT LOCATION PROBLEMS

4.1 Problem 1.- Manchester Candies Company (5)

1. Introduction (paraphrased from (5))

A British-based company, Manchester Candies, decides to build a plant for the manufacture of candies. Most of the required new materials are generally available in the United States, except for the chocolate, which is to be made from cocoa beans, milk, and other ingredients, according to Manchester's special process. The site characteristics analysis is conducted by a site selection team of three individuals: a production specialist, a personnel representative, and a plant planning engineer. The team wish to avoid embarrassing conflicts with either labor union or environment protection groups. The major location factors that the team mainly concerns are the following:

(1) Labor force - No history of labor confrontation; workers willing to do routine jobs.

(2) Transportation - Good highway network, but rail and barge connections unnecessary.

(3) Raw materials - Ready access to dairy farms, sufficient water supply, proximity to harbor for unloading cocoa beans.

(4) Climate - Unimportant except for impact on raw

material deliveries.

(5) Community - Small community preferred where the plant would become a major contribution to the local economy.

(6) Pollution - Unpolluted source of water desired; lack of local concern over pollution produced by plant.

(7) Energy - Stable supply of natural gas.

(8) Government - Sympathetic to business.

(9) Capital and operating costs - Important, but not the major consideration.

The site selection team feels that raw material is the most important factor, and the transportation factor is also a very important factor for a likely plant site. After searching through east coast area, the team selects eight sites to make further analysis. A comparison table for each of the alternatives was provided by this team (Table 4.1).

Table 4.1 A comparison study of the major factor

Sites	Attributes		
	X1 Transportation	X2 Raw material	X3 Operating cost
1	good	available	6.0 million
2	fair	available	5.8 million
3	good	limited	5.7 million
4	very good	plentiful	5.6 million
5	excellent	available	5.6 million
6	fair	limited	6.0 million
7	fair	available	5.7 million
8	very good	available	5.4 million

2. An application of the Dominance method

First, site 1 is compared with site 2. Site 1 is better than site 2 in attribute 1, equal to site 2 in attribute 2, but worse in attribute 3; so both sites are nondominated with respect to each other. Next, site 1 is compared to site 3. Site 1 is equivalent to site 3 in attribute 1, better than site 3 in attribute 2, but worse in attribute 3; neither site dominates the other. Then introduce the next alternative and so on. If one site j is dominated by site i, it can be expressed as $S_i \rightarrow S_j$. The final dominance diagram is given in Fig 4.1 through all the pairwise comparisons. Since no arrow goes into S_4, S_5, and S_8 , they are nondominated sites which need further evaluation.

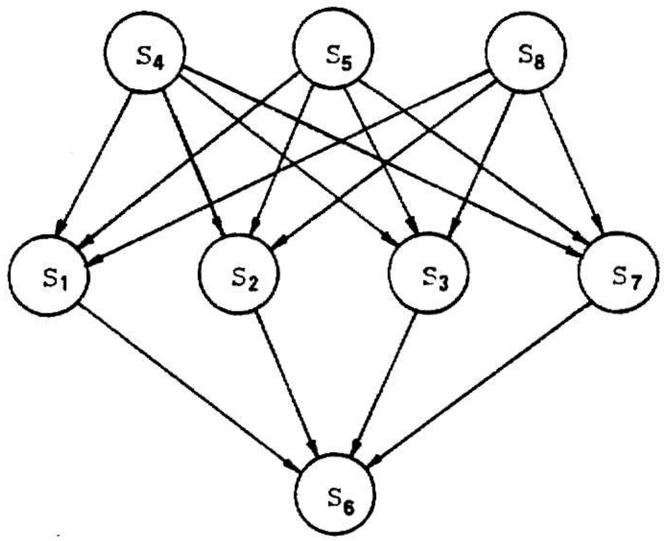


Fig 4.1 Domination diagram for Table 4.1

4.2 problem 2. - Kelly Springfield Tire Company (18)

1. Introduction (paraphrased from (18))

The Kelly Springfield Tire Company, a wholly owned subsidiary of the Goodyear Tire Corporation. At the beginning of the site search Kelly Springfield had nine tire distribution centers located throughout the United States. The site selection team anticipated that the new plant would supply tires to the distribution centers in the same proportion as the respective share that each center contributed the firm's total sales. The West coast and Central United States market demand, however, could be economically supplied from the low-cost plant, Tyler, Texas, leaving the demand in the eastern portions of the country to be supplied by the new plants. The firm had three production plants located in Freeport, Illinois; Cumberland, Maryland; and Tyler, Texas. The Illinois and Maryland plants produced 58 percent of the total automobile tires manufactured by the firm, as compared to its eastern United States market demand of 72 percent. The 14 percent shortage was made up by the Texas plant. Given the production capacity of the existing three plants and the projected market demand, the new plant would have to supply 30 percent of the projected demand. The Illinois and Maryland plants could supply 41 percent of this demand, so that the three together would supply 71 percent - almost matching the eastern market demand of 72 percent. Hence, the geographic analysis of market demand and production capacity demonstrated that the new plant should be located in the eastern part of the country.

The site selection team agreed that the minimum population range necessary to provide reasonable living conditions was an urban community of 25,000 persons having a labor supply area of 150,000 inhabitants within a radius of thirty miles. The maximum urban community should not be more than 150,000 people, since experience showed that urban areas larger than this were unlikely to provide the best labor climate for a tire plant.

After community evaluation trips involved contacting industrial developers and local industrial managers, collecting available information and visiting potential sites, of the sixteen cities visited, thirteen were eliminated by the team on the basis of one or two problems such as living conditions. After examining the locational factors: industrial climate, labor climate, transportation facilities, economic costs, living conditions, the comprehensive comparative analysis is shown in Table 4.2 .

Table 4.2 Comprehensive Comparative Analysis

Factors	Greenville	Fayetteville	Johnson City
Industrial climate	good	good	good
Labor climate			
Availability	good	good	good
Population	231,000	379,000	296,000
Productivity	fair	good	good
Unionization	extensive	little	moderate
Transportation	excellent	excellent	excellent
Economic costs (12,500 tires/day)			
Labor	3,310,000	3,310,000	3,625,000
Freight	1,982,000	2,243,000	2,019,000
Utilities	650,000	677,000	516,000
Taxes	376,000	212,000	276,000
Living conditions			
Urban population	51,000	60,000	38,000
Housing	reasonable	very good	very good
Education	fair	good	good
Hospital	good	good	good
Recreation	fair	good	good
Site conditions			
Size (acres)	235	405	210
Topograph	excellent	good	very poor
Cost ($ per acre)	1,000	1,500	1,000-2,000
Option status	in hand	in hand	avialable

2. Attribute evaluation

(1) Industrial climate: All three communities could provide an atmosphere not conditioned to any single industry, type of service, or category of employment.

(2) Labor climate: Revealed an adequate level of labor availability in each community, along with a substantial population within a thirty mile radius. The Fayetteville area had the largest potential labor supply with a population of 379,000. None of the communities possessed a sufficient supply of skilled labor. Greenville's workers were extensively organized, whereas Fayetteville showed little unionization. Johnson City's workers were moderately organized. A federal training program was just getting underway in Greenville. The oldest of fifty state-operated technical institutes for industrial training was located in Fayetteville. In addition, a $ 1 million expansion program was underway at the institute. A similar state-operated training program was located in Johnson City. The overall evluation of each community's labor climate rated Fayetteville the highest, Johnson City second, and Greenville third, primarily because of its poorer worker productivity and labor training program.

(3) Transportation facilities: The ideal site should face a good highway providing easy access to the interstate highway system to facilitate the travel of employees, custom-ers, and salesmen and the shipping of suplies, equipment, and products. The sites revealed that all had excellent highway connections.

Rail service within each community presented no problem.

(4) Economic costs: The economic analysis revealed that the three communities were almost equally competitive, with Greenville favored by a slight margin and Fayetteville the least attractive because of higher freight and utility costs.

(5) Living conditions: Fayetteville with a population of 60,000 provided better services - recently built shopping centers and a new downtown area, air terminal, and civic auditorium. Hospital and recreation facilities were adequate in all three communities. Each of the communities contained sufficient housing, but Fayetteville had many more attractive subdivisions. Therefore, Fayetteville was ranked ahead of Johnson City on living conditions, followed by Greenville.

(6) Site conditions: Three communities all met the minimum size requirement of two hundred acres. The Greenville and Fayetteville development organizations had specific site options in hand, but the Johnson City option had not been completely negotiated. The Greenville site possessed excellent topography, and the terrain of the Fayetteville site was also good. But the Johnson City site had miserable topography. Calculations based on aerial photographs showed that nearly 2 million cubic yards of earth grading would have to be completed in preparation for the plant, which would cause a sixty to ninety day delay in the construction schedule. Since production at the new plant was to start as quickly as possible, this delay, as well as the lack of a site option in hand in the first place, gave Greenville and

Fayetteville an added advantage over Johnson City. The summary of comparative rankings is presented in Table 4.3.

Attribute weight: The attribute weights are corresponding to the priority of locational factors and given by the site selection team (Fig. 4.2)

Table 4.3 Summary of comparative Rankings

Location factor		Greenville Miss (S1)	Fayetteville N. Ca (S2)	Johnson City Tenn (S3)
Industrial climate	(X1)	1	1	1
Labor climate	(X2)	3	1	2
Transportation	(X3)	1	1	1
Economic costs	(X4)			
Labor	(X41)	1	1	3
Freight	(X42)	1	3	2
Utilities	(X43)	2	3	1
Taxes	(X44)	3	1	2
Living conditions	(X5)	3	1	2
Site conditions	(X6)	1	2	3

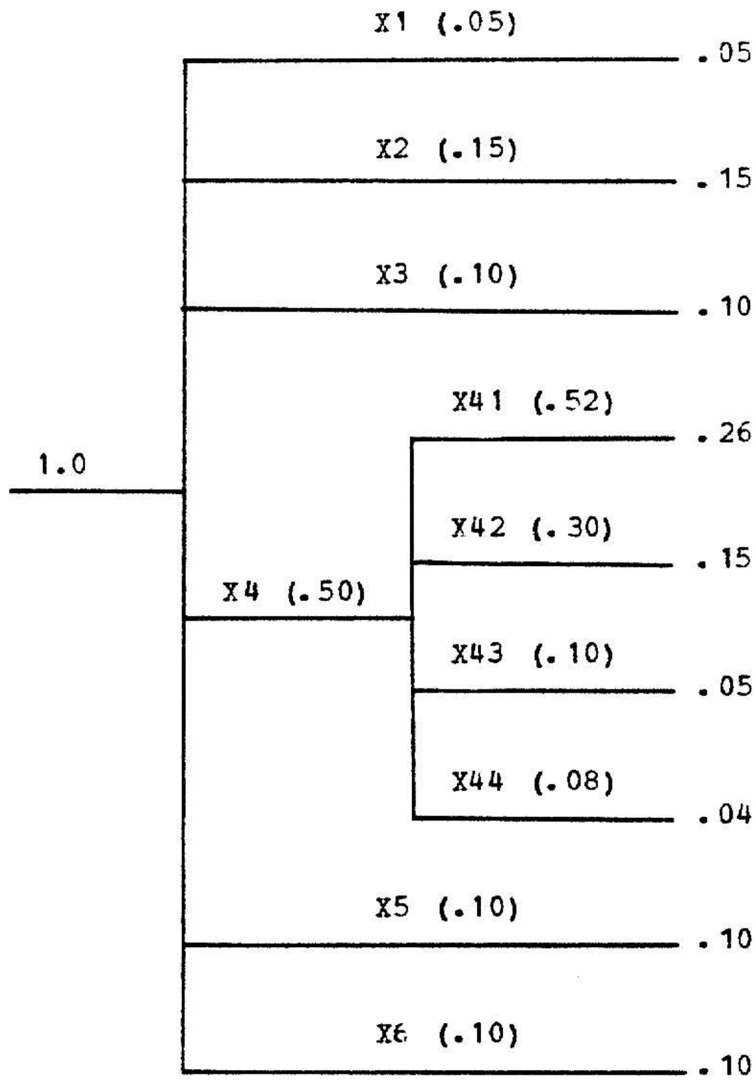


Fig. 4.2 Assessment of attribute weights

4. The application of Concensus Ranking Method

(1) From the Table 4.3, three alternatives all obtain the same rank scores on attributes X1 and X3. Excluding X1 and X3 attributes, a decision matrix is presented as follow:

	X2	X411	X412	X42	X43	X44	X5	X6
Greenville	3	1	2	1	2	3	3	1
Fayeteville	1	2	1	3	3	1	1	2
Johnson City	2	3	3	2	1	2	2	3

(2) The distance matrix can be obtained by calculating the following distance equation.

$$d_{ik} = \sum_{j=1}^{n} | a_i^j - k |$$

	1st	2nd	3rd
S1	0.760	0.670	0.940
S2	0.630	0.620	1.070
S3	1.160	0.410	0.540

(3) Using the linear assignment algorithm

$$\min \sum_{i=1}^{3} \sum_{k=1}^{3} d_{ik} X_{ik}$$

$$\text{s.t} \quad \sum_{k=1}^{3} X_{ik} = 1 \ , \ i=1,2,3$$

$$\sum_{i=1}^{3} X_{ik} = 1 \ , \ k=1,2,3$$

$$X_{ik} \geq 0 \quad \text{for all } i,k$$

(4) The optimum matrix is

	1st	2nd	3rd
S1	0	1	0
S2	1	0	0
S3	0	0	1

Thus, the ranking is (S2, S1, S3), where S2 (Fayetteville) is the best site.

4.3 Problem 3 -The location of an electrical appliance plant (26)

1. Introduction

This study is concerned with the locational decision of a single manufacturing plant and is based entirely on real world data. The plant specifications are as follows. A site of 20 - 30 acres is required, to hold a building with about 100,000 square feet of production space. A total of 450 production workers will be employed, and 10 office workers are also required. Each month the plant will use 1,200 kw and 232,000 kwh of electric power and 151,000 cubic feet of water. The annual production for which the plant is being constructed is almost 100,000 units, with a total weight of approximately 144,000 cwt. The geographical distribution of the market is illustrated in Fig 4.3. There are 81 destinations for the product, with the volume to be shipped varying from less than 50 cwt to more than 15,000 cwt. The market is largely confined to the eastern half of the country. Six components are required to manufacture the product. Their sources are indicated in Fig 4.4. The largest requirement in terms of weight is for motors, with almost 206,000 cwt to be shipped annually from a single source in the Great Lakes area. Next comes galvanized steel, with 50,000 cwt and a choice of five alternative sources. Third is metal tubes, with 15,000 cwt and source of supply in central Indiana and in Detroit. The remaining three components are capacitors, panels, and another part, which, with a combined weight of only just over 5,000 cwt to be shipped each year, have very litle bearing on location. Seven sites are selected to make the final comparative analysis which are shown in Table 4.4. Lansing (Mi) - S1, Birmingham (Ala) - S2, Atlanta (Ga) - S3, Evansville (Ind) - S4, Lexington (Ky) - S5, Columbia (S.C.) - S6, Nashiville (Tenn) - S7.

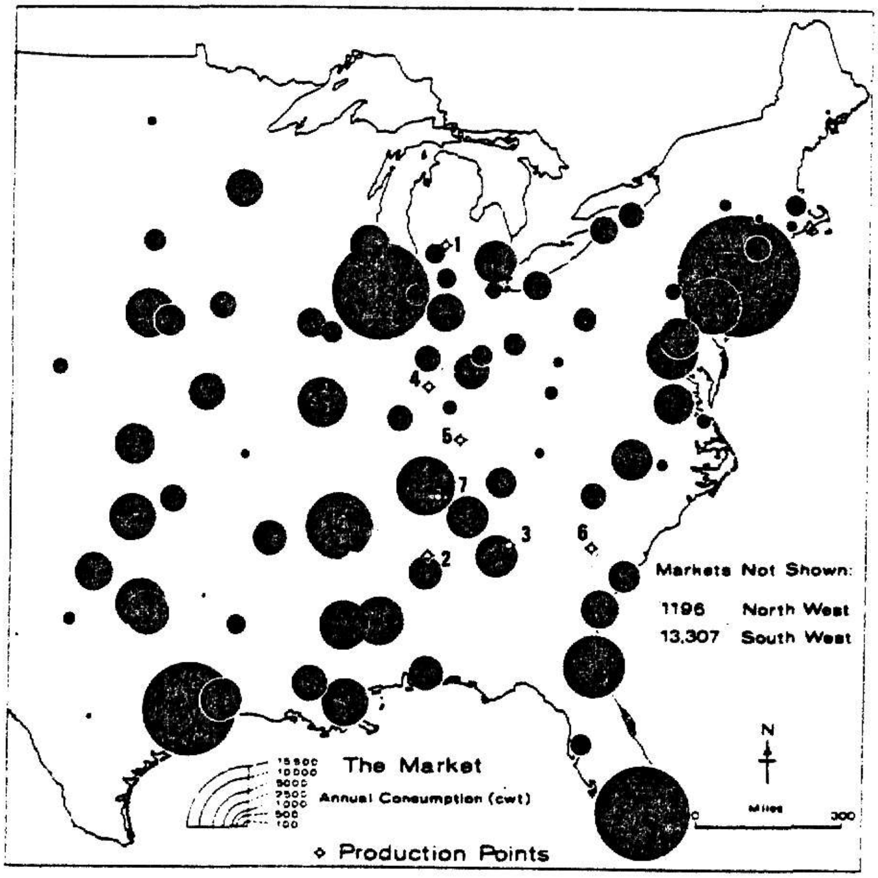


Fig 4.3 The distribution of the market and possible production points

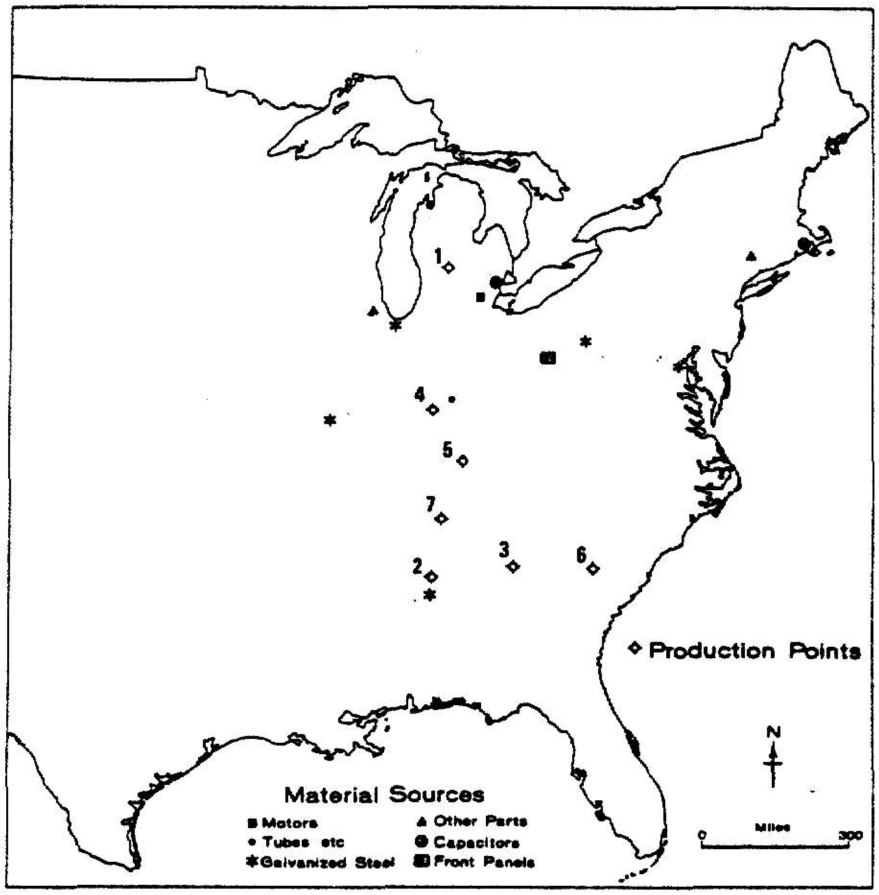


Fig 4.4 Source of materials

2. Attributes evaluation

The major location attributes that the plant would like to consider are economic impacts, functional impacts, community attitudes and quality of life. Here we list them and their components, along with the unit of measurement for each.

A. Economic impacts (X1) ($1,000)

(a) Capital costs (X11) - including the land and building cost.

(b) Annual costs (X12) - the most important factor, consists of labor, transportation, utilities, taxes, and interplant communication.

B. Functional impacts (X2)

(a) Availability of labor force (X21) (1,000)

(b) State man-days idle due to work stoppages (X22) (1,000)

(c) Union membership as a percent of non-agricultural employees (X23) (%)

(d) Transportation (X24) - railroad and truck services

C. Community attitudes

(a) State tax incentive program (X31) - There are fifteen criteria to evaluate for this attribute.

(1) Corporate income tax exemption

(2) Personal income tax exemption

(3) Excise tax exemption

(4) Tax exemption on land, capital investments

(5) Tax exemption on equipments

(6) Inventory tax exemption on goods in transit

(7) Tax exemption on manufacturers' inventories.

(8) Sales/use tax exemption on new equipments

(9) Tax exemption on raw materials used in manufacturing

(10) Tax incentives for creation of jobs

(11) Tax incentives for industrial investment

(12) Tax credits for use of specified state products

(13) Tax stabilization agreements for specified industries

(14) Tax exemption to encourage research and development

(15) Accelerated depreciation of industrial equipment

(b) State financing program (X32) - There are eleven critera to be evaluated.

(1) State sponsored industrial development authority

(2) Privately sponsored development credit corporation

(3) State authority or agency revenue bond financing

(4) State agency general obligation bond financing

(5) State loans for equipment, machinery

(6) State loans for building construction

(7) State loan guarantees for equipment and machinery

(8) State loan guarantees for building construction

(9) State financing aids for existing plant expansions

(10) State matching funds for city and/or county industrial

financing programs

(11) State incentives for establishing industrial plants in areas of high unemployment

(c) State special services for industrial development (X33) - eighteen criteria would be considered in evaluating the attributes (X33).

(1) State financed speculative building

(2) State provision of free land for industry

(3) State-owned industrial park sites

(4) State funds for city and/or county development-related public works projects

(5) State funds for city and/or county master plans

(6) State funds for city and/or county recreation projects

(7) State funds for private recreation projects

(8) State program to promote research and development

(9) State program to increase export of products

(10) University R & D facilities available to industry

(11) State and/or university conducted feasibility studies to attract or assist new industry

(12) State recruting, screening of industrial employees

(13) State retraining of industrial employees

(14) State supported training of industrial employees

(15) State supported training of "hard-core" unemployed

(16) State incentives to industry to train "hard-core" unemployed

(17) State help in bidding on federal procurement contracts

(18) State science and/or technology advisory council

(d) State incentive for pollution control (X34) - including nine criteria to be considered.

(1) Real property tax exemption

(2) Personal property tax exemption

(3) Sales/use tax exemption on purchase of pollution control facilities

(4) Sales/use tax exemption appliable to lease of pollution control facilities

(5) Credit against corporate income tax

(6) Maximum dollar limit of credit

(7) Accelerated depreciation of pollution control equipment

(8) Exclusion of pollution control investment from corporate franchise tax

(9) Exemption appliable to cost of operating pollution control facilities

(e) City and county business investment incentives (X35) - there are fifteen criteria to be considered.

(1) Tax exemption on land, capital investment

(2) Tax exemption on equipment

(3) Inventory tax exemption on goods in transit

(4) Tax exemption on manufacturers' inventories

(5) Sales/use tax exemption on new equipment

(6) Revenue bond financing

(7) General obligation bond financing

(8) Loans for building construction

(9) Equipments, machinery loans

(10) Publicly financed speculative buildings for private industry

(11) Publicly owned industrial park sites

(12) Publicly provided industrial land below cost

(13) Publicly provided industrial access roads below cost

(14) Publicly provided utilities expansion below cost

(15) Publicly provided services below cost

D. Quality of life (X4) - there are eight characteristics to be considered in determining the standard of quality of life.

(a) Climate and terrain (X41) - six criteria are used to determine a score for mildness.

(1) Very hot and very cold months

(2) Seasonal temperature variation

(3) Heating- and cooling-degree days

(4) Freezing days

(5) Zero-degree days

(6) 90-degree days

(b) Housing (X41) - three criteria are used to rank the seven metro areas for basic costs of owning a single family detached house over one year.

(1) Annual average utility bill

(2) Annual average property tax

(3) Annual average mortgage payment

(c) Health care and environment (X43) - ten criteria are used in arriving at a score for the quality of health care and environment in a metro area.

(1) Number of physicians per 100,000 residents

(2) Number of hospital beds per 100,000 residents

(3) Teaching hospitals

(4) Medical schools

(5) Health maintenance organizations

(6) Cardiac rehabilitation centers

(7) Acute stroke centers

(8) Comprehensive cancer treatment centers

(9) Fluoridation of drinking water

(10) Air pollution

(d) Crime (X44) - in ranking the seven metro areas for relative safety by two criteria.

(1) Violent crime rate

(2) Property crime rate divided by 10

The sum of these rates is the metro area's score. The higher the score, the more dangerous the metro area.

(e) Public transportation (X45) - determining a score for transportation supply is based on the metro area's ability to accomodate the transportation needs of its residents, using the following modes of travel as criteria.

(1) Air travel

(2) Passenger rail service

(3) Interstate highways

(4) Freeway mileage

(5) Urban mass-transit systems

(f) Education (X46) - the quality of local elementary and secondary school is usually the primary consideration of families who have to decide where they are going to live. The following criteria are employed to score a metro area for its ability to provide its residents with educational opportunities.

(1) Student/teacher ratio in the K-12 systems

(2) Effort index in K-12 systems

(3) Academic options in higher education

(g) Recreation (X47) - eleven criteria are used to determine a score for the access to recreation in a metro area.

(1) Public golf courses

(2) Bowling alleys

(3) Per capita expenditures on public parks and recreation

(4) Movie theaters

(5) Neighborhood bars

(6) Zoos

(7) Aquariums

(8) Family theme parks

(9) Game seats per capita for professional sports events

(10) Pari-mutual horse and dog racing

(11) Automobile racing

(h) Art (X48) - nine kinds of institutions or facilities are evaluated in arriving at a score for a metro area's cultural facilities.

(1) Major universities

(2) Symphony orchestras

(3) Opera companies

(4) Dance companies

(5) Theatres

(6) Public television stations

(7) Fine arts radio stations

(8) Museums

(9) Public libraries

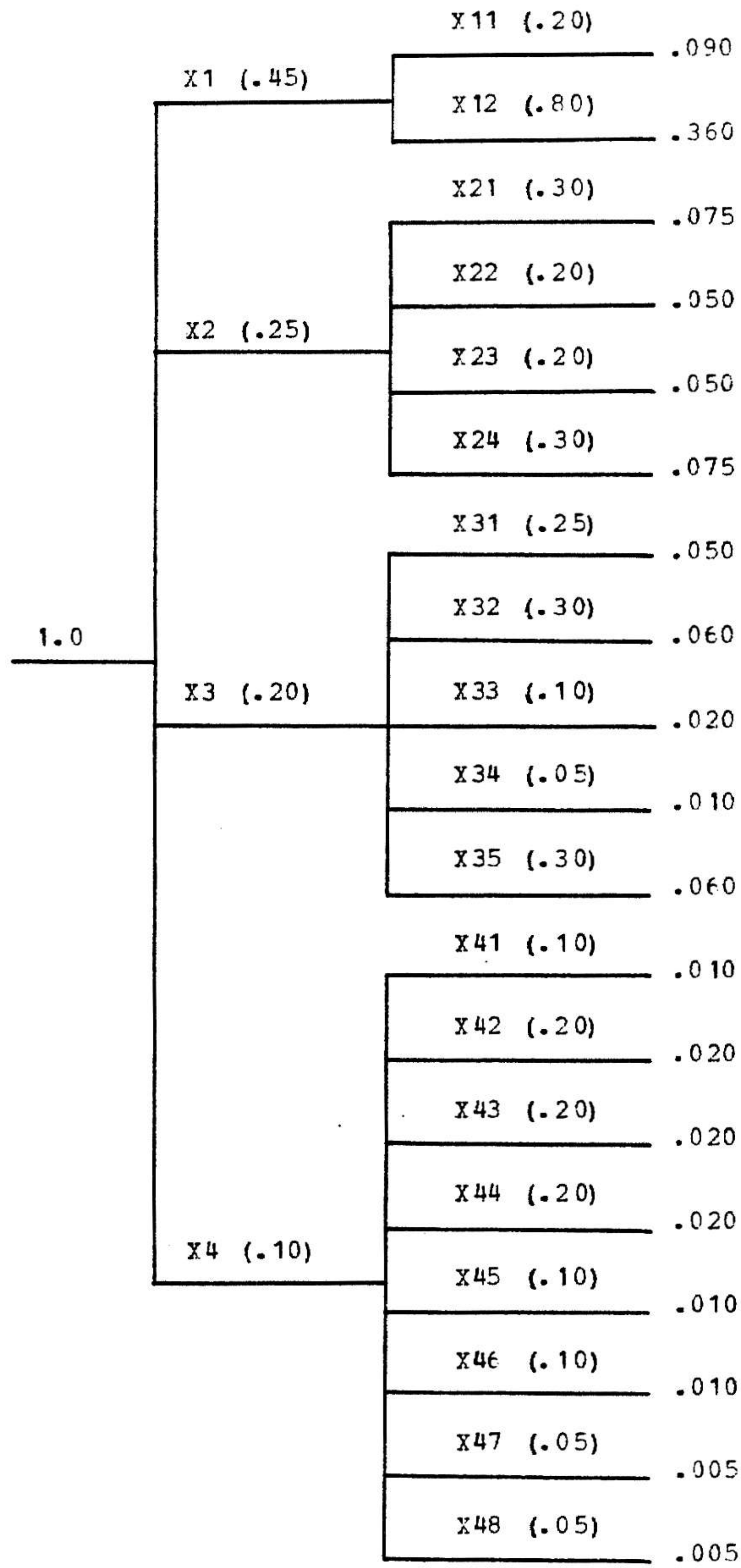


Fig 4.5 Assessment of attribute weights

Table 4.4 Final comparative analysis (4) (28)

	S1	S2	S3	S4	S5	S6	S7
X11*	64	179	188	233	242	189	243
X12*	2101	1885	1817	1941	1875	1889	1840
X21	4298	1642	2385	2620	1620	1306	2015
X22*	1593	667	470	1547	729	64	914
X23*	34.6	19.2	13.6	29.3	22.4	6.7	17.7
X24	fair	good	ideal	average	good	very good	very good
X31	10	10	6	8	9	9	10
X32	7	3	1	5	8	3	3
X33	13	13	11	14	12	11	15
X34	8	9	5	2	5	6	5
X35	3	8	4	4	1	0	5
X41	525	602	696	556	639	526	602
X42*	6244	6000	7748	4915	6568	6506	6462
X43	857	1239	2135	828	1702	1055	2108
X44*	745	1188	1572	853	826	1547	954
X45	5051	6325	14878	2738	5282	9917	8564
X46	2784	2649	2927	2773	2336	2703	2688
X47	1142	979	1569	1219	843	935	912
X48	2472	2085	4078	965	955	1421	1759

* - Cost attributes

2. An application of the TOPSIS method

Step 1. Calculate the normalized decision matrix:

The outcomes of each attribute are divided by the norm of the total outcome vector of the attribute at hand.

	S1	S2	S3	S4	S5	S6	S7
X11*	.1211	.3388	.3559	.4410	.4581	.3578	.4600
X12*	.4160	.3732	.3598	.3843	.3713	.3740	.3643
X21	.6623	.2530	.3675	.4037	.2496	.2013	.3105
X22*	.6035	.2527	.1781	.5861	.2762	.0242	.3463
X23*	.5874	.3260	.2309	.4975	.3803	.1138	.3005
X24	.2926	.3511	.5267	.2341	.3511	.4096	.4096
X31	.4218	.4218	.2531	.3374	.3796	.3796	.4218
X32	.5433	.2328	.0776	.3881	.6209	.2328	.2328
X33	.3842	.3842	.3251	.4137	.3546	.3251	.4433
X34	.4961	.5582	.3101	.1240	.3101	.3721	.3101
X35	.2621	.6990	.3495	.3495	.0874	0	.4369
X41	.3334	.3823	.4421	.3531	.4058	.3341	.3823
X42*	.3690	.3545	.4578	.2904	.3881	.3884	.3818
X43	.2145	.3101	.5343	.2072	.4259	.2640	.5275
X44*	.2463	.3927	.5197	.2820	.2731	.5114	.3154
X45	.2273	.2846	.6694	.1232	.2377	.4462	.3853
X46	.3898	.3709	.4098	.3882	.3271	.3784	.3763
X47	.3888	.3333	.5342	.4150	.2870	.3183	.3105
X48	.4237	.3573	.6989	.1654	.1637	.2435	.3015

Step 2. Calculate the weighted nomalized decision matrix:

Based on the weights given by decision maker, the weighted normalized decision matrix is

X11*	.0109	.0305	.0320	.0397	.0412	.0322	.0414
X12*	.1498	.1344	.1295	.1383	.1337	.1346	.1311
X21	.0497	.0190	.0276	.0303	.0187	.0151	.0233
X22*	.0302	.0126	.0089	.0293	.0138	.0012	.0173
X23*	.0294	.0163	.0115	.0249	.0190	.0057	.0150
X24	.0219	.0263	.0395	.0178	.0263	.0307	.0307
X31	.0211	.0211	.0127	.0169	.0190	.0190	.0211
X32	.0326	.0140	.0047	.0233	.0373	.0140	.0140
X33	.0077	.0077	.0065	.0083	.0071	.0065	.0089
X34	.0050	.0056	.0031	.0012	.0031	.0037	.0031
X35	.0157	.0419	.0210	.0210	.0052	0	.0262
X41	.0033	.0038	.0044	.0035	.0041	.0033	.0038
X42*	.0074	.0071	.0092	.0058	.0078	.0077	.0076
X43	.0043	.0062	.0107	.0041	.0085	.0053	.0106
X44*	.0049	.0079	.0104	.0056	.0055	.0102	.0063
X45	.0023	.0028	.0067	.0012	.0024	.0045	.0039
X46	.0039	.0037	.0041	.0039	.0033	.0038	.0038
X47	.0019	.0017	.0027	.0021	.0014	.0016	.0016
X48	.0021	.0018	.0035	.0008	.0008	.0012	.0015

Step 3. Determine the ideal and negative-ideal solutions:

A* = (.0109, .1295, .0497, .0012, .0057, .0395, .0211, .0373, .0089, .0056, .0419, .0044, .0058, .0107, .0049, .0067, .0041, .0027, .0035)

A⁻ = (.0414, .1498, .0151, .0302, .0294, .0178, .0127, .0047, .0065, .0012, 0, .0033, .0092, .0041, .0104, .0012, .0033, .0014, .0008)

Step 4. Calculate the separation measure:

The seperation of each site from the ideal solution can be obtained by

$$S_{i*} = \sqrt{\sum_{j=1}^{19} (V_{ij} - V_j^*)^2} \quad , i=1,2,\ldots,7$$

S_{1*} = .05387

S_{2*} = .04860

S_{3*} = .04873

S_{4*} = .06054

S_{5*} = .06168

S_{6*} = .06434

S_{7*} = .05355

Similarly, the separation of each site from the negative-ideal one can be obtained by

$$S_{i-} = \sqrt{\sum_{j=1}^{19} (V_{ij} - V_{j}^{-})^2} \quad , i=1,2,\ldots,7$$

S_{1-} = .05738

S_{2-} = .05367

S_{3-} = .04930

S_{4-} = .03608

S_{5-} = .04354

S_{6-} = .04507

S_{7-} = .04336

Step 5. Calculate the relative closeness to the ideal solution:

$$C_{i*} = S_{i-} / (S_{i*} + S_{i-}) \quad , i=1,2,\ldots,7$$

C_{1*} = .51578

C_{2*} = .52479

C_{3*} = .50291

C_{4*} = .36678

C_{5*} = .41380

C_{6*} = .4194

C_{7*} = .44743

Step 6. Rank the preference order:

According to the descending order of C_{i*}, the preference order is (S2, S1, S3, S7, S5, S6, S4). Birmingham (Ala.) would be selected as a new plant site by the site selection team.

4. An application of ELECTRE method

The first and second steps of ELECTRE are the same as those of TOPSIS. The remaining steps are presented as follows:

Step 3. Determine the concordance and discordance sets:

Concordance sets

C_{12} = (11, 21, 31, 32, 33, 44, 46, 47, 48)

C_{13} = (11, 21, 31, 32, 33, 34, 42, 44)

C_{14} = (11, 21, 24, 31, 32, 34, 43, 44, 45, 46, 48)

C_{15} = (11, 21, 31, 33, 34, 35, 42, 44, 46, 47, 48)

C_{16} = (11, 21, 31, 32, 33, 34, 35, 41, 42, 44, 46, 47, 48)

C_{17} = (11, 21, 31, 32, 34, 42, 44, 46, 47, 48)

C_{21} = (12, 22, 23, 24, 31, 33, 34, 35 ,41, 42, 43, 45)

C_{23} = (11, 31, 32, 33, 34, 35, 42, 44)

C_{24} = (11, 12, 22, 23, 24, 31, 34, 35, 41, 43, 45, 48)

C_{25} = (11, 21, 22, 24, 31, 33, 34, 35, 42, 45, 46, 47, 48)

C_{26} = (11, 12, 21, 31, 32, 33, 34, 35, 41, 42, 43, 44, 47, 48)

C_{27} = (11, 22, 31, 32, 34, 35, 41, 47, 48)

C_{31} = (12, 22, 23, 24, 35, 41, 43, 45, 46, 47, 48)

C_{32} = (12, 21, 22, 23, 24, 41, 43, 45, 46, 47, 48)

C_{34} = (11, 12, 22, 23, 24, 34, 35, 41, 43, 45, 46, 47, 48)

C_{35} = (11, 12, 21, 22, 23, 24, 34, 35, 41, 43, 45, 46, 47, 48)

C_{36} = (11, 12, 21, 24, 33, 35, 41, 43, 45, 46, 47, 48)

C_{37} = (11, 12, 21, 22, 23, 24, 34, 41, 43, 45, 46, 47, 48)

C_{41} = (11, 22, 23, 33, 35, 41, 42, 47)

C_{42} = (21, 32, 33, 42, 44, 46, 47)

C_{43} = (21, 31, 32, 33, 35, 42, 44)

C_{45} = (11, 21, 33, 35, 42, 46, 47, 48)

C_{46} = (21, 32, 33, 35, 41, 42, 44, 46, 47)

C_{47} = (11, 21, 32, 42, 44, 46, 47)

C_{51} = (12, 22, 23, 24, 32, 41, 43, 45)

C_{52} = (12, 23, 24, 32, 41, 43, 44)

C_{53} = (31, 32, 33, 34, 42, 44)

C_{54} = (12, 22, 23, 24, 31, 32, 34, 41, 43, 44, 45, 48)

C_{56} = (12, 21, 31, 32, 33, 35, 41, 43, 44)

C_{57} = (11, 22, 32, 34, 41, 44)

C_{61} = (12, 22, 23, 24, 41, 43, 45)

C_{62} = (22, 23, 24, 32, 45, 46)

C_{63} = (22, 23, 31, 32, 33, 34, 42, 44)

C_{64} = (11, 12, 22, 23, 24, 31, 34, 43, 45, 48)

C_{65} = (11, 22, 23, 24, 31, 34, 42, 45, 46, 47, 48)

C_{67} = (11, 22, 23, 24, 32, 34, 45, 46, 47)

C_{71} = (12, 22, 23, 24, 31, 33, 35, 41, 43, 45)

C_{72} = (12, 21, 23, 24, 31, 32, 33, 41, 42, 43, 44, 45, 46)

C_{73} = (31, 32, 33, 34, 35, 42, 44)

C_{74} = (12, 22, 23, 24, 31, 34, 35, 41, 43, 45, 48)

C_{75} = (12, 21, 23, 24, 31, 33, 34, 35, 42, 43, 45, 46, 47, 48)

C_{76} = (12, 21, 24, 31, 32, 33, 35, 41, 42, 43, 44, 46, 47, 48)

Discordance sets:

D_{12} = (12, 22, 23, 24, 34, 35, 41, 42, 43, 45)

D_{13} = (12, 22, 23, 24, 35, 41, 43, 45, 46, 47, 48)

D_{14} = (12, 22, 23, 33, 35, 41, 42, 47)

D_{15} = (12, 22, 23, 24, 32, 41, 43, 45)

D_{16} = (12, 22, 23, 24, 43, 45)

D_{17} = (12, 22, 23, 24, 33, 35, 41, 43, 45)

D_{21} = (11, 21, 32, 44, 46, 47, 48)

D_{23} = (12, 21, 22, 23, 24, 41, 43, 45, 46, 47, 48)

D_{24} = (21, 32, 33, 42, 44, 46, 47)

D_{25} = (12, 23, 32, 41, 43, 44)

D_{26} = (22, 23, 24, 45, 46)

D_{27} = (12, 21, 23, 24, 33, 42, 43, 44, 45, 46)

D_{31} = (11, 21, 31, 32, 33, 34, 42, 44)

D_{32} = (11, 31, 32, 33, 34, 35, 42, 44)

D_{34} = (21, 31, 32, 3, 42, 44)

D_{35} = (31, 32, 33, 42, 44)

D_{36} = (22, 23, 31, 32, 34, 42, 44)

D_{37} = (31, 32, 33, 35, 42, 44)

D_{41} = (11, 21, 24, 31, 32, 34, 43, 44, 45, 46, 48)

D_{42} = (11, 12, 22, 23, 24, 31, 34, 35, 41, 43, 45, 48)

D_{43} = (11, 12, 22, 23, 24, 34, 41, 43, 45, 46, 47, 48)

D_{45} = (12, 22, 23, 24, 31, 32, 34, 41, 43, 44, 45)

D_{46} = (11, 12, 22, 23, 24, 31, 34, 43, 45, 48)

D_{47} = (12, 22, 23, 24, 31, 33, 34, 35, 41, 43, 45, 48)

D_{51} = (11, 21, 31, 33, 34, 35, 42, 44, 46, 47, 48)

D_{52} = (11, 21, 22, 31, 33, 34, 35, 42, 45, 46, 47, 48)

D_{53} = (11, 12, 21, 23, 24, 35, 41, 43, 45, 46, 47, 48)

D_{54} = (11, 21, 33, 35, 42, 46, 47)

D_{56} = (11, 22, 23, 24, 34, 42, 45, 46, 47, 48)

D_{57} = (12, 21, 23, 24, 31, 33, 35, 42, 43, 45, 46, 47, 48)

D_{61} = (11, 21, 31, 32, 33, 34, 35, 42, 44, 46, 47, 48)

D_{62} = (11, 12, 21, 31, 33, 34, 35, 41, 42, 43, 44, 47, 48)

D_{63} = (11, 12, 21, 24, 35, 41, 43, 45, 46, 47, 48)

D_{64} = (21, 32, 33, 35, 41, 42, 44, 46, 47)

D_{65} = (12, 21, 32, 33, 35, 41, 43, 44)

D_{67} = (12, 21, 31, 33, 35, 41, 42, 43, 44, 48)

D_{71} = (11, 21, 32, 34, 42, 44, 46, 47, 48)

D_{72} = (11, 22, 34, 35, 47, 48)

D_{73} = (11, 12, 21, 22, 23, 24, 41, 43, 45, 46, 47, 48)

D_{74} = (11, 21, 32, 42, 44, 46, 47)

D_{75} = (11, 22, 32, 41, 44)

D_{76} = (11, 22, 23, 34, 45)

Step 4. Calculate the concordance matrix:

An element C of the C matrix is obtained as

$$C_{12} = \sum_{j \in C_{12}} W_j = W_{11} + W_{21} + W_{31} + W_{32} + W_{33} + W_{44} + W_{46} + W_{47} + W_{48}$$

$$= 0.335$$

Then the concordance matrix is:

C =

----	.335	.345	.425	.365	.435	.345
.735	----	.330	.790	.480	.805	.330
.655	.620	----	.755	.830	.740	.770
.575	.210	.305	----	.285	.280	.280
.635	.595	.180	.720	----	.675	.240
.575	.255	.280	.720	.375	----	.360
.705	.780	.240	.720	.770	.810	----

<u>Step 5. Calculate the discordance matrix</u>:

An element d_{12} of the D matrix is obtained as

$$d_{12} = \frac{\max_{j \in D_{12}} | V_{1j} - V_{2j} |}{\max_{j \in J} | V_{1j} - V_{2j} |}$$

$$= \frac{\max (.0154, .0176, .0131, .0044, .0006, .0262, .0005, .0003, .0019, .0005)}{\max (.0196, .0154, .0307, .0176, .0131, .0044, 0, .0186, 0, .0006, .0262, .0005, .0003, .0019, .0030, .0005, .0002, .0002, .0003)}$$

$$= \frac{.0262}{.0307} = 0.8534$$

The discordance matrix is:

	-----	.8534	.7634	.3746	.5290	.8382	.6131
	1.0	-----	.6316	.5407	.6349	.2721	.1803
	1.0	1.0	-----	.8571	1.0	.2362	.9894
D =	1.0	1.0	1.0	-----	.9810	1.0	1.0
	1.0	1.0	.4847	1.0	-----	.5708	.9013
	1.0	1.0	1.0	.7473	1.0	-----	1.0
	1.0	1.0	1.0	.7209	1.0	.6145	-----

Step 6. Determine the concordance dominance matrix:

The average concordance index is

$$\bar{C} = \frac{\sum_{p=1}^{7}\sum_{q=1}^{7} C_{pq}}{7 \times 6} = \frac{21.66}{42} = .5157$$

The concordance matrix is

	---	0	0	0	0	0	0
	1	---	0	1	0	1	0
	1	1	---	1	1	1	1
F =	1	0	0	---	0	0	0
	1	1	0	1	---	1	0
	1	0	0	1	0	---	0
	1	1	0	1	1	1	---

Step 7. Determine the discordance dominance matrix:

The average discordance index is

$$\bar{d} = \frac{\sum_{p=1}^{7} \sum_{q=1}^{7} d_{pq}}{7 \times 6} = \frac{34.4345}{42} = .8199$$

Then the discordance dominance matrix is

$$G = \begin{matrix} --- & 0 & 1 & 1 & 1 & 0 & 1 \\ 0 & --- & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & --- & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & --- & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & --- & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & --- & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & --- \end{matrix}$$

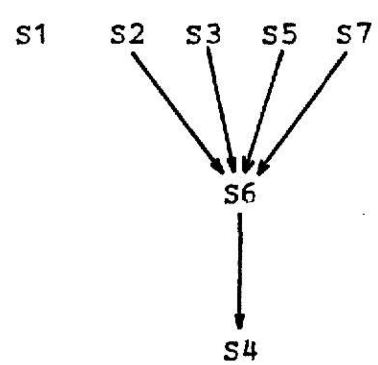
Step 8. Determine the aggregate dominance matrix:

Combining matrices of F and G, the aggregate dominance matrix is obtained as

	---	0	0	0	0	0	0
	0	---	0	1	0	1	0
	0	0	---	0	0	1	0
E =	0	0	0	---	0	0	0
	0	0	0	0	---	1	0
	0	0	0	1	0	---	0
	0	0	0	1	0	1	---

Step 9. Eliminate the less favorable alternatives:

S2 → S4, S2 → S6, S3 → S6, S5 → S6, S6 → S4, S7 → S4, S7 → S6.



From the graphical presentation, it is no help for selecting the best site among seven alternatives. In order to choose the best site, we need to make the further analysis by relaxing the threshold value (lower $\bar{c}$; increase $\bar{d}$)

If $\bar{c}$ = .3, and $\bar{d}$ = .9 are taken instead of the average concordance index of .5157 and discordance index of .8199, then the F, G, and E matrices are as follow:

	---	1	1	1	1	1	1
	1	---	1	1	1	1	1
	1	1	---	1	1	1	1
F =	1	0	1	---	0	0	0
	1	1	0	1	---	1	0
	1	0	0	1	1	---	1
	1	1	0	1	1	1	---

$$G = \begin{array}{ccccccc} --- & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & --- & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & --- & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & --- & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & --- & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & --- & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & --- \end{array}$$

$$E = \begin{array}{ccccccc} --- & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & --- & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & --- & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & --- & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & --- & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & --- & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & --- \end{array}$$

The dominance relationships become

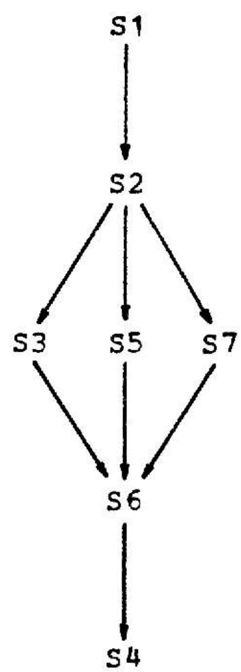
S1→S2, S1→S3, S1→S4, S1→S5, S1→S6,

S1→S7, S2→S3, S2→S4, S2→S5, S2→S6,

S2→S7, S3→S4, S3→S6,

S5→S6, S6→S4, S7→S4, S7→S6.

S1 is left as the nondominated site. The final graphical representation as follow:



We can easily see that S1 is a nondominated site. But we cannot tell the preference relation among S3, S5, and S7.

4.5 Problem 4 - Decision process

1. Introduction

After the site selection team chooses the best site among the finite alternatives, the president of the company must decide on whether to build or not to build the new manufacturing plant.

The factors which affect the selection of a good site are given in a hierarchy (Fig 4.6). The hierarchy consists of four levels, the first hierarchy level has a single objective; a good site (GS). The second hierarchy level has four objectives; less cost (LC), higher productivity (HP), better community attitudes (BC), and better living (BL). Their priorities are derived from a matrix of pairwise comparisons with respect to the objective of the first level. The third hierarchy level objectives are the location factors; capital cost (C), labor (L), transportation (T), facilities (F), utilities (U), tax incentive program (TI), financing program (FP), special service for industrial development (S), education (E), recreation (RE), health care and environment (HE), and housing (H). The fourth hierarchy level is the operational level; there are two actions: build a new manufacturing plant (B), and renovate the present facility (R).

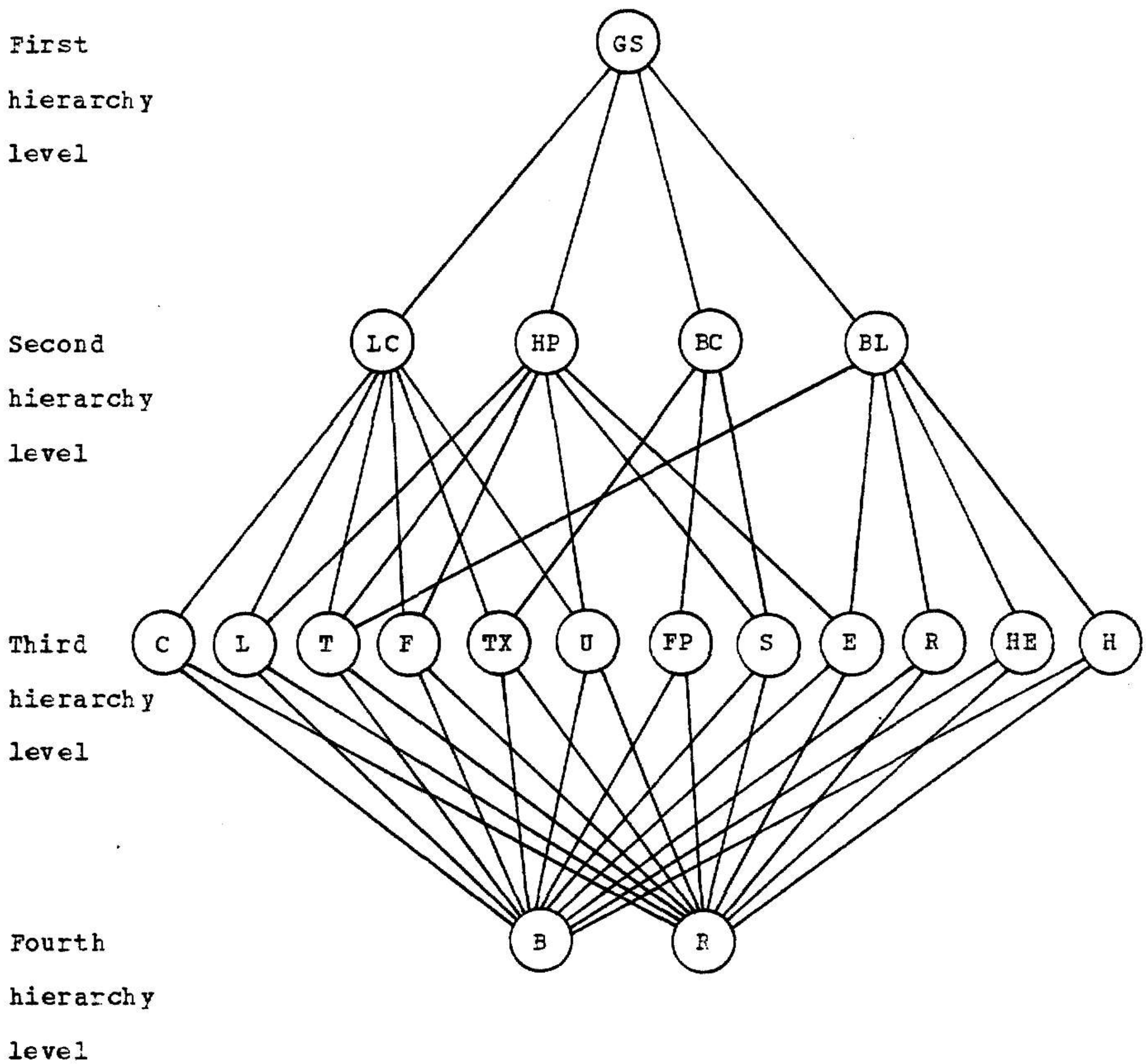


Fig 4.6 A hierarchy of a good site

2. An application of the Analytical Hierarchical Process

The president's judgement in a matrix form is as follows:

Level 2.

GS	LC	HP	BC	BL
LC	1	2	4	6
HP	1/2	1	2	4
BC	1/4	1/2	1	3
BL	1/6	1/4	1/3	1

This matrix indicates that less cost is 2 times stronger than higher productivity, 4 times stronger than better community attitudes, and 6 times stronger than better living, etc.

Level 3.

LC	C	L	T	U	TX	F
C	1	1/6	1/3	1/2	1/2	1
L	6	1	3	5	6	7
T	3	1/3	1	3	5	6
U	2	1/5	1/3	1	1	2
TX	2	1/6	1/5	1	1	2
F	1	1/7	1/6	1/2	1/2	1

HP	L	T	F	U	S	E
L	1	3	2	5	5	4
T	1/3	1	1/2	1	2	3
F	1/2	2	1	2	3	4
U	1/5	1	1/2	1	2	3
S	1/5	1/2	1/3	1/2	1	1
E	1/4	1/3	1/4	1/3	1	1

BC	TX	FP	S
TX	1	2	4
FP	1/2	1	2
S	1/4	1/2	1

BL	T	E	R	HE	H
T	1	2	2	1	1/2
E	1/2	1	1	1/2	1/2
R	1/2	1	1	1/2	1/3
HE	1	2	2	1	1
H	2	2	3	1	1

Level 4.

L	G	N
G	1	1/8
N	8	1

C	G	N
G	1	2
N	1/2	1

T	G	N
G	1	6
N	1/6	1

F	G	N
G	1	1/2
N	2	1

TX	G	N
G	1	3
N	1/3	1

U	G	N
G	1	2
N	1/2	1

FP	G	N
G	1	3
N	1/3	1

S	G	N
G	1	2
N	1/2	1

E	G	N
G	1	1
N	1	1

R	G	N
G	1	3
N	1/3	1

HE	G	N
G	1	3
N	1/3	1

H	G	N
G	1	4
N	1/4	1

The eigenvector of the first matrix is given by

$$B_2 = \begin{array}{c} \\ LC \\ HP \\ BC \\ BL \end{array} \begin{array}{c} GS \\ \left[\begin{array}{c} .51 \\ .27 \\ .15 \\ .07 \end{array}\right] \end{array}$$

The eigenvector for level 3 is given by

$$B_3 = \begin{array}{c} \\ C \\ L \\ T \\ F \\ TX \\ U \\ FP \\ S \\ E \\ R \\ HE \\ H \end{array} \begin{array}{c} \begin{array}{cccc} LC & HP & BC & BL \end{array} \\ \left[\begin{array}{cccc} .06 & 0 & 0 & 0 \\ .46 & .40 & 0 & 0 \\ .25 & .13 & 0 & .21 \\ .05 & .22 & 0 & 0 \\ .08 & 0 & .57 & 0 \\ .09 & .12 & 0 & 0 \\ 0 & 0 & .29 & 0 \\ 0 & .07 & .14 & 0 \\ 0 & .06 & 0 & .12 \\ 0 & 0 & 0 & .11 \\ 0 & 0 & 0 & .24 \\ 0 & 0 & 0 & .31 \end{array}\right] \end{array}$$

The eigenvectors for level 4 is given by

$$B_4 = \begin{matrix} & C & L & T & F & TX & U & FP & S & E & R & HE & H \\ B & .67 & .89 & .86 & .67 & .75 & .67 & .75 & .67 & .50 & .75 & .75 & .80 \\ R & .33 & .11 & .14 & .33 & .25 & .33 & .25 & .33 & .50 & .25 & .25 & .20 \end{matrix}$$

The final composite vector of influences on a good site obtained from the product $B_4 \cdot B_3 \cdot B_2$ is given by

$$W = \begin{matrix} & GS \\ B & .80 \\ R & .20 \end{matrix}$$

Thus, the overall priority of building a new manufacturing plant is .80, and that of renovating the present plant is .20. The president finally decides to build a new manufacturing plant.

4.5 Problem 5 - Multiplant location strategy

1. Introduction

An electronics manufacturing company wants to build as many plants as possible in the United States. The case to be studied is a comparison of costs at ten sites. The capital costs consist of expenditures involved in the acquisition of land, facilities, and construction of plants.

The analysis of labor cost is confined to wage earners, since it is assumed that the salaries of managerial personnel will be the same regardless of location.

Transportation costs can be subdivided into the inbound and outbound components. Five materials (steel-strip(coils), brass and copper strip, aluminum strip, plastic laminated sheels, and screw machine parts) are involved in the inbound freight bill. In calculating the outbound freight costs, the estimate of the cost was based on the shipments of the finished goods.

The utilities bill includes the cost of power, water, and fuel.

Local and state taxes could be estimated with the assistance of the local officials.

When all these factors have been evaluated, the estimates of total costs for the first year (X1) can be calculated for each location. Suppose that the total budget of 28 million is allocated over a set of ten prospective sites whose estimated costs are

S1 = $ 7.0 million, S2 = $ 4.0 milliom, S3 = $ 5.0 million,

S4 = $ 5.0 million, S5 = $ 3.0 million, S6 = $ 4.5 million,

S7 = $ 10.0 million, S8 = $ 5.5 million, S9 = $ 6.0 million,

S10 = $ 6.0 million.

In order to make the final analysis, the attributes higher productivity (X2), better community relationship (X3), and better living (X4) also are evaluated.

2. An application of the Ordinal Intersection method

Let the priority order for the selected attributes be X1, X2, X3, and X4. The attributewise rankings for the chosen four attributes are as follow:

R1 = (5, 2, 6, 4, 8, 9, | 1, 3, 8, 10)

R2 = (4, 8, 3, 5, | 1, 2, 10, 5, 6, 7)

R3 = (6, 5, 4, 3, 2, | 1, 9, 10, 7, 8)

R4 = (2, 4, 9, 5, 3, | 7, 6, 8, 1, 10)

The vertical line (|) indicates the cut-off point, given the available budget of 28 millions. For example, under attribute 1, the first six sites - that is sites 5, 2, 6, 4, 8, and 9, form the fundable set. Thus

f1 = (5, 2, 6, 4, 8, 9)

f2 = (4, 8, 3, 5)

f3 = (6, 5, 4, 3, 2)

f4 = (2, 4, 9, 5, 3)

Case 1. Assume that the four attributes have been ranked in the natural ordering with equal weights. That is, attribute 1 is preferred to attribute 2 is preferred to attribute 3, etc.

Level 1 - four attributes

$$\bigcap_{i=1}^{4} f_i = (4, 5) \quad , \quad g = (4, 5)$$

The total budget consumed by these two plants is S4 + S5 = $ 8 million. Since some budget remains, the process can be proceeded to intersections of three attributes.

Level 2 - three attributes

$$f_1 \cap f_2 \cap f_3 = (4, 5)$$
$$f_1 \cap f_2 \cap f_4 = (4, 5)$$
$$f_1 \cap f_3 \cap f_4 = (2, 4, 5) \quad , \quad g = (4, 5, 2)$$

If plant 2 is added, the total budget consumed to date is S2 + S4 + S5 = $12 million. Next,

$$f_2 \cap f_3 \cap f_4 = (3, 4, 5) \quad , \quad g = (4, 5, 2, 3)$$

If Plant 3 is added, the total budget consumed to date is S2 + S3 + S4 + S5 = $ 21 million.

Level 3 - two attributes

$$f_1 \cap f_2 = (4, 5, 8) \quad , \quad g = (4, 5, 2, 3, 8)$$

If plant 8 is added, the total budget consumed is S2 + S3 + S4 + S5 + S8 = $ 26.5 million.

Since the remaining \$ 1.5 million is not sufficient for any of the remaining sites, the process is finished. The best set of sites is g = (4, 5, 2, 3, 8).

Case 2 - with the weight on each attribute

Assume that the DM has assigned the weights (0.45, 0.25, 0.15, 0.15) to attributes X1, X2, X3, and X4.

Level 1 - four attributes

$$\bigcap_{i=1}^{4} f_i = (4, 5) \quad , \quad g = (4, 5)$$

The total budget consumed by these two plants is S4 + S5 = \$ 8 million. Since the budget left is enough to locate some more plants, the process goes on to the next subset of f whose sum of weights is highest among all remaining subsets. The list, in descending order of sum-of-weights, of the intersections of f taking 2 and 3 at a time is:

$f_1 \cap f_2 \cap f_3 = (4, 5)$, sum of weights = 0.85

$f_1 \cap f_2 \cap f_4 = (4, 5)$, sum of weights = 0.85

$f_1 \cap f_3 \cap f_4 = (2, 4, 5)$, sum of weights = 0.75

$f_1 \cap f_2 = (4, 5, 8)$, sum of weights = 0.70

$f_1 \cap f_3 = (2, 4, 5, 6)$, sum of weights = 0.60

$f_1 \cap f_4 = (2, 4, 5, 9)$, sum of weights = 0.60

$f_2 \cap f_3 \cap f_4 = (3, 4, 5)$, sum of weights = 0.55

$f_2 \cap f_3 = (3, 4, 5)$, sum of weights = 0.40

$f_2 \cap f_4 = (3, 4, 5)$, sum of weights = 0.40

$f_3 \cap f_4 = (2, 3, 4, 5)$, sum of weights = 0.30

The highest sum-of-weights contributors are

$$f_1 \cap f_2 \cap f_3 = (4, 5) ,$$

$$f_1 \cap f_2 \cap f_4 = (4, 5) ,$$

$$f_1 \cap f_3 \cap f_4 = (2, 4, 5) ,$$

of which, the first two add nothing to the previous g, whereas the third one adds plant 2. Thus the new g is (4, 5, 2) and the total budget consumed to date is S2 + S4 + S5 = $ 12 million.

$$f_1 \cap f_2 = (4, 5, 8) ,$$

Plant 8 is added. Thus the new g is (4, 5, 2, 8) and the total budget consumed to date is S2 + S4 + S5 + S8 = $ 17.5 million.

$$f_1 \cap f_3 = (2, 4, 5, 6) ,$$

Plant 8 is added. Thus the new g is (4, 5, 2, 8, 6) and the total budget consumed is S2 + S4 + S5 + S6 + S8 = $ 22 million.

$$f_1 \cap f_4 = (2, 4, 5, 9) ,$$

Plant 9 is added. Thus the new g is (4, 5, 2, 8, 6, 9) and the total budget consumed to date is S2 + S4 + S5 + S6 + S8 + S9 = $ 28 million.

Since the total budget consumed is $ 28 millions, the process is finished. The best set of sites is given by

g = (S4, S5, S2, S8, S6, S9).

CONCLUSION

There were two primary objectives of this study: (1) to identify the factors which have important influence on manufacturing investors in making site selections for their plants, (2) to propose some useful MADM techniques for the site selection problems. The major factors considered in the determination of a plant location are (1) less cost, (2) higher productivity, (3) better community attitudes, and (4) better quality of life. These factors are conflicting with each other very frequently. So, the MADM methods are very helpful in evaluating and selecting one from the finite number of alternatives with the properties of incommensurable units, conflict among attributes, intangible and qualitative attributes.

Seven methods are chosen to solve the different levels/versions of plant location problems. Screening, solution, and decision levels make up the systematic process diagram (Fig 5.1). A complete process can be summarized as follow:

(1) The plant location problem may begin with obtaining a number of prospective sites from many states. The Dominance method will be introduced to reduce the set of sites by eliminating the dominated sites.

(2) For the purpose of selecting a balancing alternative, the decision maker needs to put the minimum level of requirement for each attribute and uses the

Conjunctive method to divide the sites into acceptable and unacceptable sites.

(3) Some particular plant location problems may contain mostly qualitative attributes, while many other location problems may consist of mostly quantitative attributes. When the problem includes mostly quantitative data, the TOPSIS method and/or ELECTRE method are employed. When most of the location factors have the difficulty to be expressed quantitatively, the Consensus Ranking method is suggested.

(4) In the final decision, the decision maker should make the decision on whether to locate a new manufacturing plant to the best site recommended by a plant location committee. Hence, the decision requires the decision maker's judgement. The Analytical Hierarchy Process suggested by Satty would be helpful for dealing with the final decision making process.

(5) Dealing with the multiplant strategy, each member of site selection team can go through the described process above and obtain a ordered set. Then, aggregating all the ordered sets, the company will obtain a fundable set of prospective sites by applying the Ordinal Intersection method.

Most MADM methods require weight information from the DM. In order to make reliable weight assessments, some methods are suggested by Hwang and Yoon (14). Different MADM methods involve various types of assumptions, weighting information requirements, and evaluation principles. Each method evaluates problems from a different point of view; none of them has been shown superior under all circumstances. Sometimes the results could be significantly different just because of applying different MADM methods. For example, there would be slightly different results between using the TOPSIS and the ELECTRE methods on the problem 3. TOPSIS method evaluates alternatives by the relative closeness to the ideal solution, and ELECTRE method provides concordance and discordance measures to judge alternatives. Obviously, the selection of an appropriate method itself is a MADM problem. Hwang and Yoon first proposed a unified approach to problems by employing several methods simultaneously instead of selecting the most appropriate method. The idea came from that a combination of methods is often more effective than a single method.

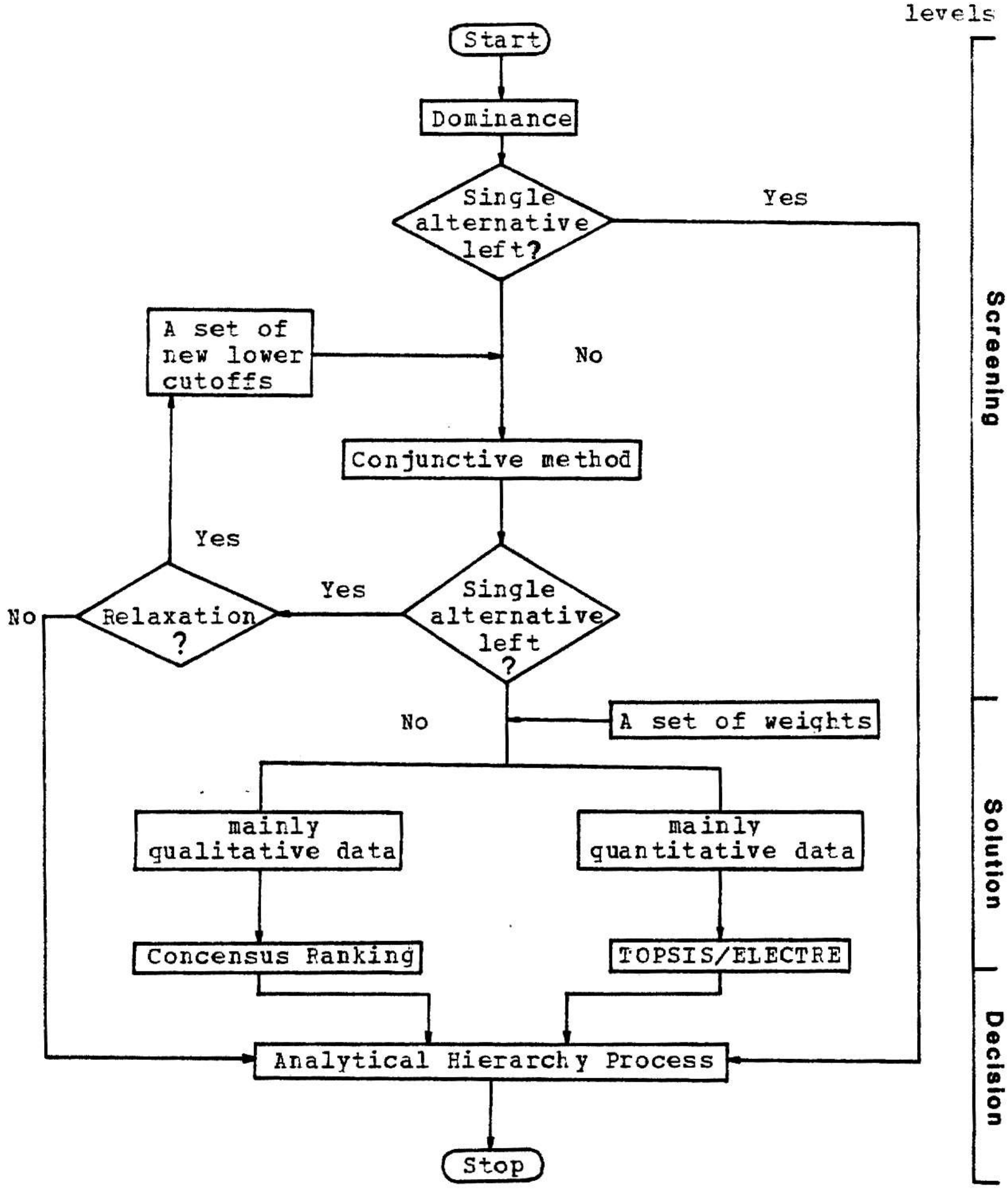


Fig 5.1 Systematic process diagram for plant location

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Site Selection of Manufacturing Plants
by Multiple Attributes Decision Making Methods

by

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Taipei, Taiwan, 1980

AN ABSTRACT OF MASTER'S THESIS

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ABSTRACT

A new manufacturing plant location problems typically involves multiple criteria and ought to be modeled as such. So decision maker must consider all these attributes in making a location analysis. The location factors include four major categories: economic impacts (less cost), functional impacts (higher productivity), community attitudes (better relationship), and quality of life (better living). Multiple Attributes Decision Making methods seem to be appropriate techniques for evaluating and/or selecting a preferred one from the finite number of alternatives, which are characterized by multiple attributes. This study has dealt with applications of MADM methods to site selection problems. Methods used in this thesis are Dominance method, Conjunctive method, the Consensus Ranking method, TOPSIS method, the Analytical Hierarchy Process, and the Ordinal Intersection method. A complete process for single plant location problem is composed of three levels. They are: screening level, solution level, and decision level.

Screening level: Dominance method and Conjunctive method are employed to eliminate the dominated alternatives.

Solution level: Consensus Ranking method, TOPSIS, and ELECTRE methods are applied to get the preference order/solution.

Decision level: The Analytical Hierarchy Process is suggested to make the decision on whether to build a new plant.

The MADM methods are applied to five versions of manufacturing plant location problems (1) too many prospective sites, (2) single plant with qualitative data, (3) single plant with quantitative data, (4) final decision - relocate or not, and (5) multiple plants strategy. The results show that the preference orders obtained might be slightly different by using the difference MADM methods. Therefore, the weighting scheme and DM's judgement, and the methods employed are playing two most important roles in the plant location problems.