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IE 302 FACILITIES DESIGN AND LOCATION COURSE READING NOTES PART 1

WHERE TO PRODUCE: FACILITY LOCATION

INTRODUCTION

Our discussion of different aspects of a production system design has so far assumed as given the location of the physical structure, whether we deal with new facilities or the expansion of existing ones. The selection of location, however, is one of the most far- reaching top management decisions for the following reasons:

1. It involves the long-term investment of large amounts of capital under conditions of considerable uncertainty.
2. It determines a rather permanent framework of operating constraints (legal, labor, community, etc.) that may be difficult and costly to change.
3. It has significant consequences on the competitive position or viability of an organization by setting a minimum limit on the cost for production and distribution to desired markets. This is especially true for service systems that must be near the customers they serve, e.g. restaurants or movie theaters.

In addition, the final solution interacts strongly with other critical decisions considered in systems design such as facilities layout. It is therefore important to consider thoroughly all the economic, technological, social, and legal factors that will influence the choice of location.

THE LOCATION PROBLEM

Briefly, the location problem consists of selecting a site for new facilities that will minimize the production and distribution cost of products and/or services to potential customers. Such a problem may arise under different conditions, which prompt management to consider alternative solutions. The final decision is usually based on the evaluation of both objective and subjective factors for each alternative site.

Reasons for Considering Location Problems
For a new firm selecting a location is an inevitable decision in the phase of system design. Here the options include the selection of a site for building new facilities or the rent or purchase of existing ones. For an existing organization, the motivation to consider the location problem may be attributed to economic, technological, social, or political factors.

The most important reasons for the need to change or expand to a new location are the following:

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1. Significant changes in the level of demand
2. Significant changes in the geographical distribution of demand
3. Changes in the costs or quality requirements of critical production inputs (labor, raw materials, energy, or other)
4. Significant increases in the real-estate value of existing or adjacent sites or in their taxation
5. Need to change as a result of fire or flood or for reasons of prestige or improved public relations

Even though the selection of a new location represents a serious planning effort, for well- organized firms it is advisable to review location problems periodically in the light of significant changes in environmental conditions.

Alternatives to New Location

Of the reasons listed above, the most common is an upward trend in the level of demand. Before undertaking a detailed study for selecting a new location, however, it is advisable to examine some alternatives for meeting the expected increase in demand, which include:

1. The increase of existing capacity by additional shifts or overtime, especially for capital-intensive systems
2. The use of seasonal inventories to reduce the need for maintaining capacity for peak demand
3. The use of subcontractors
4. The purchase of new equipment for the present location with a less expensive facilities expansion

For limited or temporary changes in demand, the above alternatives, usually considered in aggregate planning, represent more economical means of expanding capacity. Otherwise, the location problem is a very real one and a feasibility study is usually undertaken by a team of specialists or external consultants.

Significant Factors in Location Studies

As already suggested, the factors considered in location problems may relate to key production inputs, to the process technology, or to the environment.

Production inputs: The incentive to move or expand to a new location may derive from the need to secure a larger quantity or different quality inputs such as labor, raw materials, energy, or other. These considerations are related to the markets of such inputs.

Raw materials: For many firms, especially in manufacturing, a dominant factor in plant location is the need to be near the sources of raw materials. This is especially true when processing results in significant weight reduction, e.g. firms engaged in mining iron ore, copper, or marble and firms processing forest products. Proximity to the source of raw materials is also important for industries that process or package perishable items (dairy products, fresh fruit, or vegetables, etc.).

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In general, an industry using an analytic process, in which raw material is broken down in successive stages to produce different products, say a lumber mill, tend to locate near the source of such an input (see Fig.la). On the other hand, for a *synthetic process,* which combines a variety of materials, components, and parts in successive stages to assemble a finished product, there is a tendency to locate near the market (see Fig. 1b).

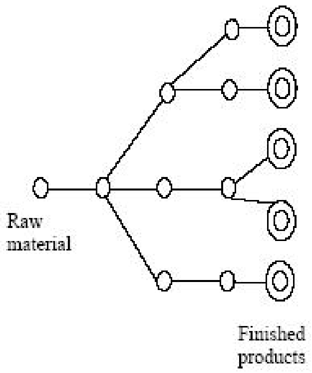


Figure 1a. Structure of analytic processes

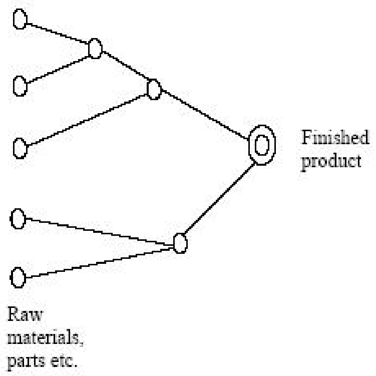


Figure 1b. Structure of synthetic processes

Services in the private sector show a strong tendency to locate near the market of potential customers. This would be true of a bank, a restaurant, a theater, or an auto-repair service. For the public sector, however, the location of services is affected both by the geographical distribution of the need for a service (schools, hospitals, fire or police stations) and by budget limitations on the degree of desired decentralization (courts, internal revenue offices, etc.).

Human resources: For many firms with unique or very large labor requirements, proximity to the appropriate labor market becomes a dominant factor in the selection of a location. Accordingly, labor-intensive organizations like large assembly-line factories or large insurance companies tend to locate in or near large metropolitan areas. Similarly, technical consulting firms gravitate to large universities for securing the needed expertise more easily. In addition to prevailing wages and salaries, location also determines the attractiveness of a firm according to the time required to commute to work. In some cities, this may be so long and tiresome that it may discourage potential employees.

The importance of labor may be reduced when it is possible to automate or mechanize one or more stages of the production process. This represents a substitution of capital for labor, which is possible through technological advances. Numerically controlled equipment in manufacturing, printed circuits in electronics, and computers for data processing in large office companies are just a few examples of this possibility. The same result is possible when management can draw on a mobile or seasonal labor market, as in harvesting farms or operating tourist resort areas.

At times the wish to reduce labor costs places unwarranted emphasis on alternatives for location in a foreign country where wages are quite low. The cost of labor as an input, however, must be examined together with labor productivity, because despite low wages in some foreign locations, the accompanying low productivity results in higher overall production costs.

Process technology: For some firms the technology used may restrict the number of locations to sites that provide an abundant low-cost supply of some critical input, such as water for pulp and paper mills or electrical energy for an aluminum plant or electrochemical plating process. Occasionally, in addition to large amounts, of certain inputs there is an added requirement for meeting strict quality specifications. For example, water that may be suitable for human consumption may not be appropriate for certain industrial uses such as steel manufacturing.

Environmental factors: Beyond the consideration of factors related to the production process and its critical inputs, the location decision depends on several factors that define the external environment:

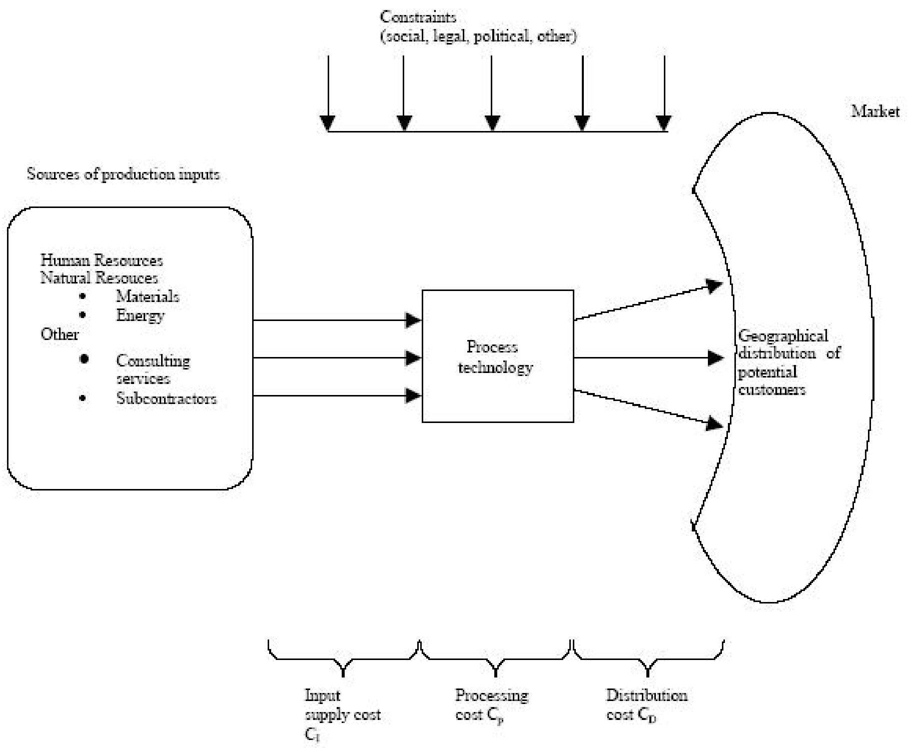
1. *The availability and reliability of supporting systems*, including public utilities for power and water, fire protection, easy transportation routes to suppliers and consumers, rapid and reliable communication, etc. Examination of these factors is especially important for the location of a new plant in a foreign country, whose economic infrastructure may lag significantly behind that of industrialized countries. Foreign investors have been discouraged from establishing new facilities in certain countries because long-distance calls may take 3 to 5 days to place, delivery of supplies is unreliable due to poor transportation, and other difficulties.

2. *Social and cultural conditions* may at times discourage the selection of a location that could pass any economic- and technical-feasibility criterion. It is thus necessary to understand the local population not only in terms of demographic variables (size. distribution, age. migration shifts, etc.) but also in terms of their attitudes toward domestic or foreign new industry and the quality, availability and reliability of potential employees. Certain traditions and customs, especially abroad, may interfere, with known ways of doing business. In several countries, for example, informal communication networks and personal relationships play a more dominant role than formalized procedures and plans.

3. *Legal and political considerations* represent a wide variety of restrictions *or* opportunities and must be studied very carefully before making a final choice. In some locations there are very strict laws pertaining to pollution standards, zoning codes, construction specifications, or import regulations. These restrictions may make it difficult to operate with existing technologies at a profit. Also, certain states or communities provide a wide variety of incentives to attract new employers. These may include reduced taxes, purchase discounts for construction sites, and less elaborate licensing procedures for new installations. One cannot overemphasize the importance of competent legal advice before making any final decisions on locating new facilities.

Formulation of the Location Problem

In order to formulate the location problem more precisely, it is helpful to view the operations system under study in relationship to its market and its sources of supply, i.e. its economic environment. This is shown in Fig. 2, where some of the most important costs that must be estimated for alternative location sites include:



1. The cost of procurement of needed production inputs C_1 that is, the cost of raw materials, labor, energy, etc. (mainly variable costs)
2. The cost of processing the inputs given the technology C_p, that is the overhead cost (mainly fixed costs)

3. The distribution cost involved in shipping product(s) or making services available to customers C_D (mainly variable costs)

These costs are tangible; i.e. they can be estimated for different locations using standard economic analysis. In addition, we must take into account certain intangible costs related to the quality of the labor available in each location, the degree of cooperation and the attitudes of the local government and community, possible relocation adjustments, and others. Finally, there is an opportunity cost for each location resulting from failure to select the best site possible if time and money impose no restrictions in the search for alternatives.

Our formulation of the *location problem* can now be made more complete and precise. Management has the task *of selecting among candidate locations the one that satisfies existing technological, legal, and other constraints and minimizes the combined cost of the relevant tangible, intangible, and opportunity costs.* In practice, intangible costs can be estimated only subjectively for each location, whereas opportunity costs are likely to be ignored in most studies.

A PRACTICAL SYSTEMS APPROACH TO LOCATION SELECTION

As we have seen, the problem of selecting a location is characterized by numerous factors with complex interrelationships. Several of these factors can be evaluated only qualitatively at best. Furthermore, the information needed is often incomplete due to the inherent difficulty of predicting future conditions. Various sophisticated techniques developed to solve parts of the total problem include linear programming, heuristic and simulation models based on some dominant objective, such as minimizing distribution costs.

Management, however, needs an approach that looks at the whole problem and allows for the careful evaluation of both quantitative and qualitative factors. This can be attempted within the framework of a systems analysis, which must cover the components shown in Figure 3.

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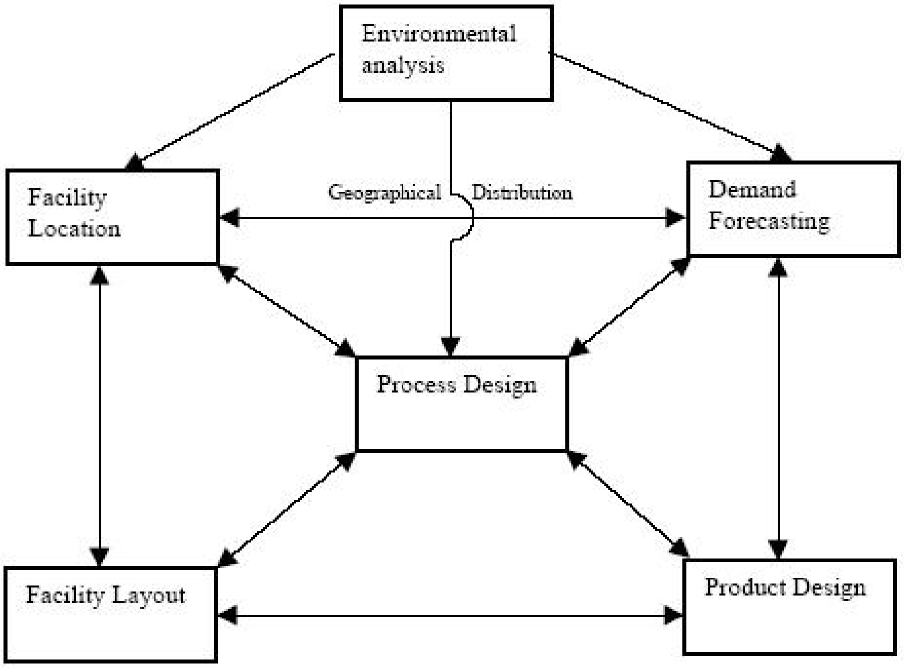

Figure 3 Interacting factors in the selection of location.

In practice, it is often useful to study the location problem in two phases, as shown in Fig. 4. First, there is a preliminary *feasibility study*, whose purpose is to determine whether the environmental changes are important enough to warrant a more detailed analysis. Thus phase one is mainly concerned with the study of trends in the level and geographical distribution of aggregate demand to determine whether they justify the minimum economical addition to capacity obtained by building new facilities.

Along with demand, the preliminary study focuses on other environmental factors such as the availability of critical production inputs, their current and projected costs, and any demographic changes that may affect the distribution of demand and/or the availability of labor or other resources. If the results of phase one justify the need for a more detailed analysis, management can proceed with phase two, which is conducted in three successive stages, as explained below.

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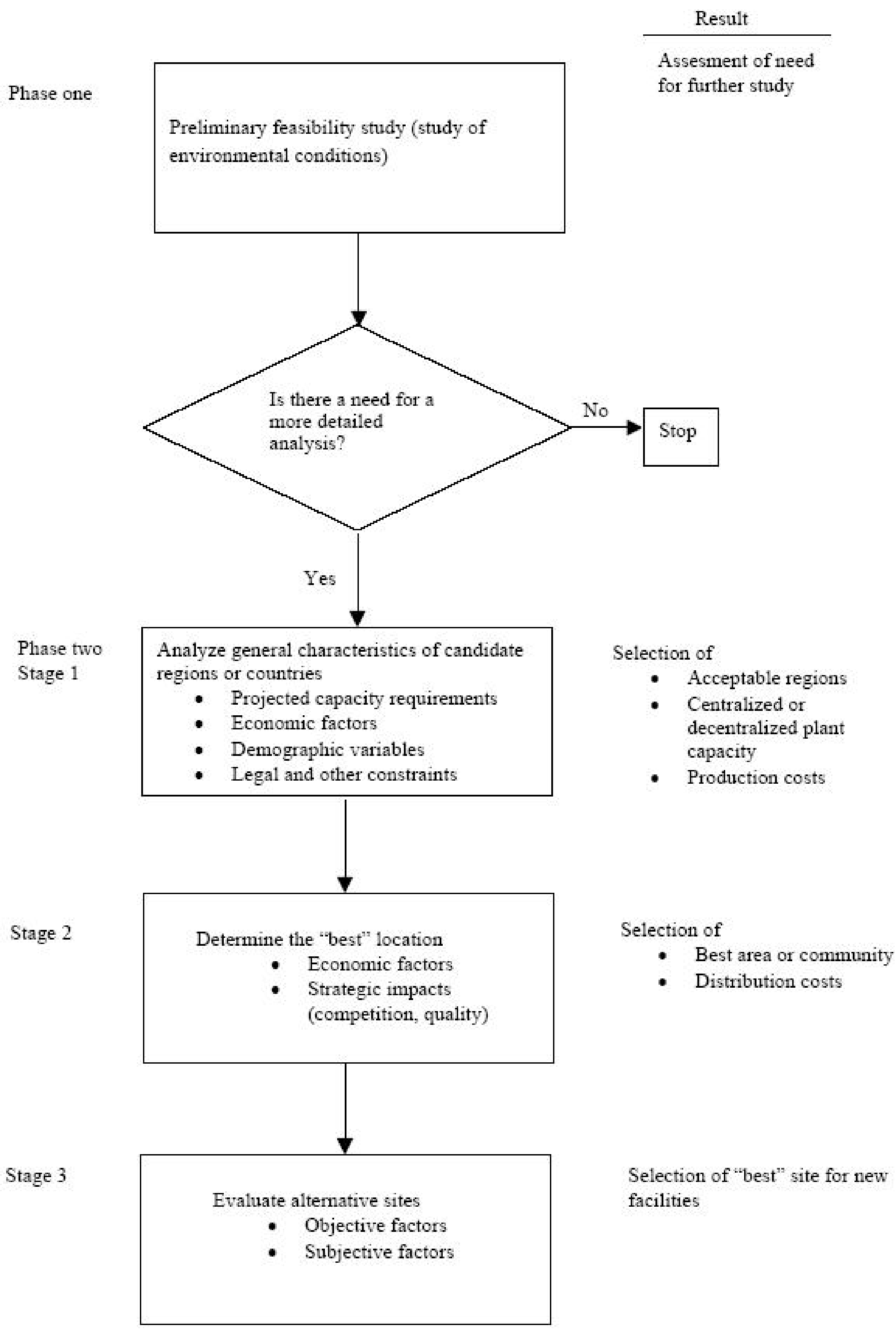

Figure 4. Procedure for selecting a location for new facilities

Stage 1: Analysis and Evaluation of Alternative Regions (or Countries)

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In stage 1 of phase two we examine a number of general characteristics for different geographic regions or countries as they relate to the scope of the firm's present and/or proposed activities. The purpose here is to select the most suitable region and to determine the capacity needed for the new facilities.

First, the marketing-research department or a special group for this task must prepare estimates of the expected increase in demand for each region of the market, using a 5 to 10-yr forecast. These estimates are then translated into requirements for new or additional productive capacity. Given an estimate of future capacity requirements, we proceed to identify alternative regions for which profits or other measure of effectiveness will be maximized for the proposed capacity. For specific demand levels and prices, profits are determined from the analysis of costs for production and distribution. Thus in stage 1 we must consider the alternatives of meeting new capacity requirements from one centralized large installation or two or more smaller-capacity facilities geographically dispersed to reduce transportation costs.

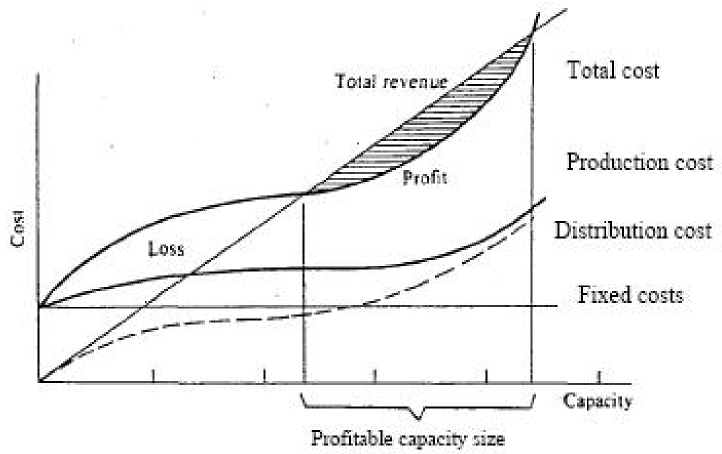

Figure. 5 Relationship of production and distribution cost curves and revenue curve for facilities of different capacity.

Figure 5 shows the relevant trade-offs. To obtain lower production costs we must achieve economies of scale made possible by larger-capacity plants. This pressure for capacity concentration, however, results in larger distribution costs due to the larger distances for product deliveries, compared with several small plants geographically dispersed. The optimum configuration is selected from an economic analysis aimed at identifying the minimum production-distribution cost alternative combined with other considerations for greater flexibility and reliability usually in favor of decentralized arrangements.
The data needed to select the most suitable region(s) and the new capacity requirements include the following:

A. Future increase in demand by region translated into productive-capacity requirements
B. Cost relationships for production and distribution
C. Identification of sources of needed production inputs:
 1. Raw materials (quality, quantity, cost, reliability)
 2. Labor market (available skills, wages, and supply levels)
 3. Supporting systems, i.e., economic infrastructure, for supplying
  a. Energy (sources, adequacy, cost)

   b. Water (quality, quantity, and cost)
   c. Transportation and communication networks (adequacy, reliability, cost)
4. Legal, social, and political factors
5. Environmental considerations (pollution, climate, quality of life)

According to Yasseen almost all elements contributing to cost can be affected up to 10 percent of the total for production and distribution by the selection of the geographic region.

Stage 2: Determination of Optimum Area for Location

After selecting the most suitable geographical region (or foreign country) and the optimum-capacity plant, the analysis continues at the level of specific areas within the region. If our criterion for selecting the best area is profit maximization, then with production costs already determined in stage 1 the maximization of profit can now be achieved by minimizing the cost of distribution.

Consider the case of a new firm about to select the location for its new facilities. First, we subdivide the market to be served by the new plant into different sections and estimate for different areas the distances and projected requirements to cover future demand. For a given location let

n = number of market sections to be covered by new plant from that location

D_j = amount of monthly deliveries to section *j* (j = 1, 2,.... n)

r_j = distance of section *j* from plant location

c_j = unit shipping cost per unit distance to destination j

Then

$c_j r_j D_j$ = monthly distribution cost to cover expected demand for market section *j* from given location

$\sum_{j=1}^{n} c_j r_j D_j$ = total monthly distribution cost for entire future market and given location

This measure can be evaluated for each alternative location to choose the one, which minimizes the total annual distribution cost.

For an existing firm, which operates one or more facilities, the situation is more complicated in that demand for various market sections can be met from the old as well as the new location(s). This type of problem has been solved by the transportation method of linear programming. To illustrate it with a simple example, let us assume that the firm under study has an old plant and is considering building a new one with capacity equal to 60 units/month in location A, B, or C. The data needed are summarized below:

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Source	Market Selection 1	Market Selection 2	Market Selection 3	Capacity available, units/month
Old Plant	$c_{11}=5$ X_{11}	$c_{12}=3$ X_{12}	$c_{13}=8$ X_{13}	$S_1=40$
New Plant	$c_{21}=5$ X_{21}	$c_{22}=5$ X_{22}	$c_{23}=5$ X_{23}	$S_2=60$
Projected demand, units month	$D_1=30$	$D_2=20$	$D_3=50$	100 / 100

Note that:
c_{ij} = cost of shipping one unit from plant I to market section j
X_{ij} = number of units shipped monthly from plant i to j
D_j = amount of monthly deliveries needed for market section j
S_i = capacity available per month in plant i

By substituting the cost values for c_{ij} that apply to the three areas A. B, and C and solving the transportation problem repeatedly, we can determine which of the three locations results in the minimum transportation cost per week.

Whether the area selection is made by straightforward economic analysis or a mathematical model, it is important to conduct a sensitivity analysis to determine whether the area selected maintains its relative advantage over other locations under different operating conditions or changes in market characteristics.

Stage 3: Community and Site Selection

Within the area chosen in stage 2 it is desirable to consider alternative sites for the construction of the new facilities. At this point, it is important to secure detailed economic and demographic data, but most factors that must be analyzed in area and site selection relate to technical, social, and legal considerations.

The factors that must be considered in the selection of a community and a site for a new location can be classified as follows:

A. Projected requirements in production inputs
1. Human resources (skills, amounts, quality)
2. Raw materials, parts, semifinished components
3. Energy, water, and other services
4. Transportation and communication facilities
5. Physical space for planned facilities and future expansion

B. Objective factors that will affect the cost and profits of new installation
1. Projected levels of annual demand
2. Projected annual operating costs

a. Costs for purchase and transportation of raw materials
b. Costs for wages of required skills
c. Costs for requirements in energy (electricity, oil. etc.), water, telephone, etc.
d. Taxes on (sales, income, property, inventories, etc.).
e. Cost for construction of new facilities

4. Estimates of annual profits for successive years
5. Cost of purchasing construction site

C. Subjective factors that will influence the community and site selection

1. Existing laws that will affect the firm's activities
2. Labor-market, characteristics
3. Transportation networks
4. Supporting infrastructure systems (power, telephone, water, waste treatment. or other)
5. Community characteristics

a. Population makeup, attitudes, traditions
b. Financial institutions
c. Cultural activities, schools, recreation
d. Quality of Life (noise, congestion, air pollution, etc)
e. Housing
d. Services

Evaluation of these factors is difficult because of the problems of (1) estimating objective factors with accuracy, (2) assigning priorities to subjective factors that defy measurement, and (3) coping with the uncertainty about the future impacts of present decisions when the stakes are so high.

Logistics management can be defined as the management of the transportation and distribution of goods (Russell and Taylor 1995). The term *goods* includes raw materials or subassemblies obtained from suppliers as well as finished goods shipped from plants to warehouses or customers. The logistics management includes all distribution and transportation activities from suppliers through to customers. Similar to the definition of material handling in Chapter 11, logistics management is the management of a series of macro-level transportation and distribution activities with the main objective of delivering

the right amount of material at the right place at the right time at the right cost using the right methods. The decisions typically encountered in logistics management concern facility location, transportation, and goods handling and storage.

Logistics management problems can be classified into three categories:

1. Location problems
2. Allocation problems
3. Location-allocation problems

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Location problems involve determining the location of one or more new facilities in one or more of several potential sites. Obviously, the number of sites must at least equal the number of new facilities being located. The cost of locating each new facility at each of the potential sites is assumed to be known. It is the fixed cost of locating a new facility at a particular site plus the operating and transportation cost of serving customers from this facility-site combination.

Allocation problems assume that the number and location of facilities are known a priori and attempt to determine how each customer is to be served. In other words, given the demand for goods at each customer center, the production or supply capacities at each facility, and the cost of serving each customer from each facility, the allocation problem determines how much each facility is to supply to each customer center.

Location-allocation problems involve determining not only how much each customer is to receive from each facility but also the number of facilities along with their locations and capacities.

Facility location problems can be classified as single-facility and multifacility problems. As the name implies, single-facility location problems deal with the optimal determination of the location of a single facility, and multifacility location problems deal with the simultaneous location determination for more than one facility. Generally single-facility location problems are location problems, but multifacility problems can be location as well as location- allocation problems (Hax and Candea 1984).

Another classification of location problems is based on whether the set of possible locations for a facility is finite or infinite. If a facility can be located anywhere within the confines of a geographic area, then the number of possible locations is infinite, and such a problem is called a continuous space location problem. In contrast, discrete space location problems have a finite feasible set of sites in which to locate a facility. The continuous space problem assumes that the transportation costs are proportional to distance. Because facilities can be located anywhere in a two-dimensional space, sometimes the optimal location provided by the continuous space model may be infeasible. For example, a continuous space model may locate a manufacturing facility on a lake! Therefore, for most real-world problems, the discrete space models are more appropriate (Hax and Candea 1984).

TECHNIQUES FOR DISCRETE SPACE LOCATION PROBLEMS

Our focus is primarily on the single-facility location problem. We provide both discrete space and continuous space models. The single facility for which we seek a location may be the only one that will serve all the customers, or it may be an addition to a network of existing facilities that are already serving customers.

Qualitative Analysis

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The location scoring method is a very popular, subjective decision-making tool that is relatively easy to use. It consists of these steps:

Step 1 *List all the factors that are important—that have an impact on the location decision.*
Step 2 *Assign an appropriate weight (typically between 0 and 1) to each factor based on the relative importance of each.*
Step 3 *Assign a score (typically between 0 and 100) to each location with respect to each factor identified in step 1.*
Step 4 *Compute the weighted score for each factor for each location by multiplying its weight by the corresponding score.*
Step 5 *Compute the sum of the weighted scores for each location and choose a location based on these scores.*

Although step 5 calls for the location decision to be made solely on the basis of the weighted scores, those scores were arrived at in a subjective manner, and hence a final location decision must also take into account objective measures such as transportation costs, loads, and operating costs. Quantitative methods that consider some of these measures are discussed in the following section (Quantitative Analysis).

Example 1

A payroll processing company has recently won several major contracts in the midwest region of the United States and central Canada and wants to open a new, large facility to serve these areas. Because customer service is so important, the company wants to be as near its "customers" as possible. A preliminary investigation has shown that Minneapolis, Winnipeg, and Springfield, Illinois, are the three most desirable locations, and the payroll company has to select one of these. A subsequent thorough investigation of each location with respect to eight important factors generated the raw scores and weights listed in the following table. Using the location scoring method, determine the best location for the new payroll processing facility.

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Factors and weights for the three locations			Score		
	Weight	*Factor*	Minneapolis	Winnipeg	Springfield
	0.25	*Proximity to customer*	95	90	65
	0.15	*Land and construction prices*	60	60	90
	0.15	*Wage rates*	70	45	60
	0.10	*Property taxes*	70	90	70
	0.10	*Business taxes*	80	90	85
	0.10	*Commercial travel*	80	65	75
	0.08	*Insurance costs*	70	95	60
	0.07	*Office services*	90	90	80

Solution Step 1, 2, and 3 have been completed. We now need to compute the weighted score for each location-factor pair (step 4), add these weighted scores and determine the location based on the scores (step 5). From the analysis below, it is clear that Minneapolis is the best location based on the subjective information given.

Weighted Scores for the three locations		Score		
	Factor	Minneapolis	Winnipeg	Springfield
	Proximity to customer	23.75	22.50	16.25
	Land and construction prices	9.00	9.00	13.50
	Wage rates	10.50	6.75	9.00
	Property taxes	7.00	9.00	7.00
	Business taxes	8.00	9.00	8.50
	Commercial travel	8.00	6.50	7.50
	Insurance costs	5.60	7.60	4.80
	Office services	6.30	6.30	5.60
	Sum of the weighted scores	78.15	76.65	72.15

Of course, as we mentioned before, objective measures must be considered, too, especially because the weighted scores for Minneapolis and Winnipeg are close.

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Quantitative Analysis

Several quantitative techniques are available to solve the discrete space, single-facility location problem. Each is appropriate for a specific set of objectives and constraints. For example, the so-called minimax location model is appropriate for determining the location of an emergency service facility, where the objective is to minimize the maximum distance traveled between the facility and any customer. Similarly, if the objective is to minimize the total distance traveled, the transportation model is appropriate. In this section we discuss the transportation model in detail and briefly describe the minimax location model.

The transportation model is well known and described in many introductory operations research textbooks, including Winston (1994) and Hillier and Lieberman (1995). Therefore we do not describe the model or the algorithm in detail but note that the model is typically used to determine the optimal distribution of goods between a given set of "plants" and a known set of "customers" so as to minimize the overall cost of transporting goods between the plants and customers while satisfying customer demand and plant supply constraints. The reader may be wondering: If the set of plants including their locations is given, where is the location problem? To answer this question, consider the following problem: We have m plants in a distribution network that serves n customers. Due to an increase in demand at one or more of these n customers, it has become necessary to open an additional plant. The new plant could be located at p possible sites. To evaluate which of the p sites will minimize distribution (transportation) costs, we can set up p transportation models, each with n customers and m + 1 plants, where the (m + 1)th plant corresponds to the new location being evaluated. Solving the model will tell us not only the distribution of goods from the m + 1 plants (including the new one from the location being evaluated) but also the cost of the distribution. The location that yields the least overall distribution cost is the one where the new facility should be located. This is illustrated in Example 2.

Example 2

Seers Inc. has two manufacturing plants at Albany and Little Rock that supply Canmore brand refrigerators to four distribution centers in Boston, Philadelphia, Galveston, and Raleigh. Due to an increase in the demand for this brand of refrigerators that is expected to last for several years, Seers Inc. has decided to build another plant in Atlanta or Pittsburgh. The unit transportation costs, expected demand at the four distribution centers and the maximum capacity at the Albany and Little Rock plants are given in the following table. Determine which of the two locations, Atlanta or Pittsburgh, is suitable for the new plant. Seers Inc. wishes to utilize all of the capacity available at its Albany and Little Rock locations.

Factors and weights for the three locations	**Demand**					
	Location	***Boston***	**Philadelphia**	**Galveston**	**Raleigh**	**Supply Capacity**
	Albany	10	15	22	20	250
	Little Rock	19	15	10	9	300
	Atlanta	21	11	13	6	No Limit
	Pittsburgh	17	8	18	12	No Limit
	Total	200	100	300	280	

Solution We must set up two transportation models: first assuming that the new plant will be located in Atlanta and second in Pittsburgh. These two models are displayed below. Notice that the maximum capacity of the new plant required at either location is 330 because the capacity at Albany and Little Rock is to be fully utilized. Solving the model using the well- known transportation algorithm, yields total costs of $7980 and $9510 when the new plant is located in Atlanta and Pittsburgh, respectively. In both cases the distribution pattern (not shown) remains the same, with Boston receiving all of its shipments from Albany, Galveston from Little Rock, Raleigh from the new plant, and Philadelphia receiving 50 units from Albany and 50 from the new plant. Because the Atlanta location also minimizes the cost, the decision is to construct the new plant in Atlanta.

Transportation model with plant in Atlanta	**Demand**					
	Location	***Boston***	**Philadelphia**	**Galveston**	**Raleigh**	**Supply Capacity**
	Albany	10	15	22	20	250
	Little Rock	19	15	10	9	300
	Atlanta	21	11	13	6	330
	Total	200	100	300	280	880

Transportation model with plant in Pittsburgh	**Demand**					
	Location	***Boston***	**Philadelphia**	**Galveston**	**Raleigh**	**Supply Capacity**
	Albany	10	15	22	20	250
	Little Rock	19	15	10	9	300
	Pittsburgh	17	8	18	12	330
	Total	200	100	300	280	880

We mentioned earlier that the location of an emergency facility such as a fire station, police station, or hospital can be treated as a minimax location problem if the objective is to minimize the maximum distance traveled or the "cost" incurred by any customer. We now show how such a problem can be solved trivially by inspecting a cost or distance matrix. Consider the problem of locating a fire station in a county.

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Assume that we have *m* possible sites and that the county can be divided into *n* locations based on population. The distance between the centroid of each of the n locations and each potential site for the fire station is shown in this distance matrix:

Location

$$\text{Site} \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{21} & \cdots & d_{2n} \\ \vdots & \vdots & \vdots & \\ d_{m1} & d_{m2} & \cdots & d_{mn} \end{bmatrix}$$

To find the optimal location we simply need to scan each row for the maximum distance and choose the site corresponding to the row that has the smallest maximum distance. This location ensures that the maximum distance that needs to be traveled by any customer is minimized.

Hybrid Analysis

A disadvantage of the qualitative method discussed in Qualitative Analysis section is that a location decision is made based entirely on a subjective evaluation. Although the quantitative method overcomes this disadvantage, it does not allow us to incorporate unquantifiable factors that have a major impact on the location decision. For example, the quantitative techniques can easily consider transportation and operational costs, but intangible factors, such as the attitude of a community toward businesses, potential labor unrest, and reliability of auxiliary service providers, though important in choosing a location, are difficult to capture. We need a method that incorporates subjective as well as quantifiable cost and other factors.

In this section we discuss a multi-attribute, single-facility location model based on the ones presented by Brown and Gibson (1972) and Buffa and Sarin (1987). This model classifies the objective and subjective factors important to the specific location problem being addressed as:

- Critical;
- Objective;
- Subjective.

The meaning of the latter two factors is obvious, but the meaning of critical factors needs some discussion. In every location decision, usually at least one factor determines whether or not a location will be considered for further evaluation. For example, if water is used extensively in a manufacturing process (e.g., a brewery), then a site that does not have an adequate water supply now or in the future is automatically removed from consideration. This is an example of a critical factor. Some factors can be objective and critical or subjective and critical. For example, the adequacy of skilled labor may be a critical factor as well as a subjective factor.

After the factors are classified, they are assigned numeric values:

$$CF_{ij} \begin{cases} 1 \text{ if location satisfies critical factor j} \\ 0 \text{ otherwise} \end{cases}$$

OF_{ij} cost of objective factor j at location i

SF_{ij} numeric value assigned (on a scale of 0-1) to subjective factor j for location I

W_j weight assigned to subjective factor j ($0 \leq w_j \leq 1$)

Let us assume that we have *m* candidate locations and *p* critical, *q* objective, and *r* subjective factors. We can determine the overall critical factor measure (CFM), objective factor measure (OFM) and subjective factor measure (SFM) for each location *i* with these equations:

$$CFM_i = CF_{i1}\, CF_{i2} \cdots CF_{ip} = \prod_{j=1}^{p} CF_{ij} \qquad i = 1, 2, \ldots, m \tag{1}$$

$$OFM_i = \frac{\max_i \left[\sum_{j=1}^{q} OF_{ij}\right] - \sum_{j=1}^{q} OF_{ij}}{\max_i \left[\sum_{j=1}^{q} OF_{ij}\right] - \min_i \left[\sum_{j=1}^{q} OF_{ij}\right]} \qquad i = 1, 2, \ldots, m \tag{2}$$

$$SFM_i = \sum_{j=1}^{r} w_j SF_{ij} \qquad i = 1, 2, \ldots, m \tag{3}$$

The location measure LM_i for each location is then calculated as:

$$LM_i = CFM\,[\alpha\, OFM_i + (1-\alpha)\, SFM_i] \tag{4}$$

where α is the weight assigned to the objective factor measure. Notice that even if one critical factor is not satisfied by a location *i*, then CFM_i and hence LMi are equal to zero. The OFM_i values are calculated so that the location with the maximum $\Sigma_j OF_{ij}$ gets an OFM_i value of zero and the one with the smallest $\Sigma_j OF_{ij}$ value gets an OFM_i value of one. Equation (4) assumes that the objective factors are cost-based. If any of these factors are profit-based, then a negative sign has to be placed in front of each such objective factor and Equation (4) can still be used. This works because maximizing a linear profit function z is the same as minimizing -z. (The following example illustrates how profit-based as well as cost-based objective factors can be incorporated into the same model.)

After LM_i is determined for each candidate location, the next step is to select the one with the greatest LM_i value. Because the a weight is subjectively assigned by the user, it may be a good idea for the user to evaluate the LM_i values for various appropriate a weights, analyze the trade-off between objective and subjective measures, and choose a location based on this analysis.

Example 3

Mole-Sun Brewing company is evaluating six candidate locations—Montreal, Plattsburgh, Ottawa, Albany, Rochester, and Kingston—for a new brewery. The two critical, three objective, and four subjective factors that management wishes to incorporate in its decision making are summarized in Table 13.7. The weights of the subjective factors are also provided in the table. Determine the best location if the subjective factors are to be weighted 50% more than the objective factors.

Solution Clearly, $\alpha = 0.4$ so that the weight of the subjective factors ($1 - \alpha = 0.6$) is 50% more than that of the objective factors. To determine OFM_i we first determine the $\Sigma_j\ OF_{ij}$ values as shown in the following tables and then ascertain the maximum and minimum of these to be -35 and -95, respectively. From these two values, it is easy to calculate OFM_i values using Equation (2). For example, for the Montreal location,

$$OFM = \frac{-35 - (-67)}{-35 - (-95)} = 0.53$$

Similarly the SFM, values are determined for each row in the following table, using the information available in the last four columns and Equation (3). Once again, for the Montreal location,

$$SFM = (0.3)\ (0.4) + (0.4)\ (0.8) + (0.25)\ (0.2) + (0.05)\ (0.8) = 0.53$$

Using the CFM_i, OFM_i, and SFM_i values, we get the location measure LM_i. The values are shown in tables below. Based on an α value of 0.4, the Plattsburgh location seems favorable. However, as the weight of the objective factors, α, increases to more than 0.6, the Montreal location becomes attractive.

	Critical		Objective			Subjective			
Location	Water Supply	Tax Incentives	Revenue	Labor Cost	Energy Cost	Community Attitude 0.3	Ease of Transportation 0.4	Labor Unionization 0.25	Support Services 0.05
Albany	0	1	185	80	10	0.5	0.9	0.6	0.7
Kingston	1	1	150	100	15	0.6	0.7	0.7	0.75
Montreal	1	1	170	90	13	0.4	0.8	0.2	0.8
Ottawa	1	0	200	100	15	0.5	0.4	0.4	0.8
Plattsburgh	1	1	140	75	8	0.9	0.9	0.9	0.55
Rochester	1	1	150	75	11	0.7	0.65	0.4	0.8

Critical			Objective				Subjective					
Location	Water Supply	Tax Incentives	Revenue	Labor Cost	Energy Cost	Sum of objective factors	Community Attitude 0.3	Ease of Transportation 0.4	Labor Unionization 0.25	Support Services 0.05	SFMi	LMi
Albany	0	1	185	80	10	95	0.5	0.9	0.6	0.7	0.7	0
Kingston	1	1	150	100	15	35	0.6	0.7	0.7	0.75	0.67	0.4
Montreal	1	1	170	90	13	67	0.4	0.8	0.2	0.8	0.53	0.53
Ottawa	1	0	200	100	15	85	0.5	0.4	0.4	0.8	0.45	0
Plattsburgh	1	1	140	75	8	57	0.9	0.9	0.9	0.55	0.88	0.68
Rochester	1	1	150	75	11	64	0.7	0.65	0.4	0.8	0.61	0.56

The Brown-Gibson Approach for Site Selection

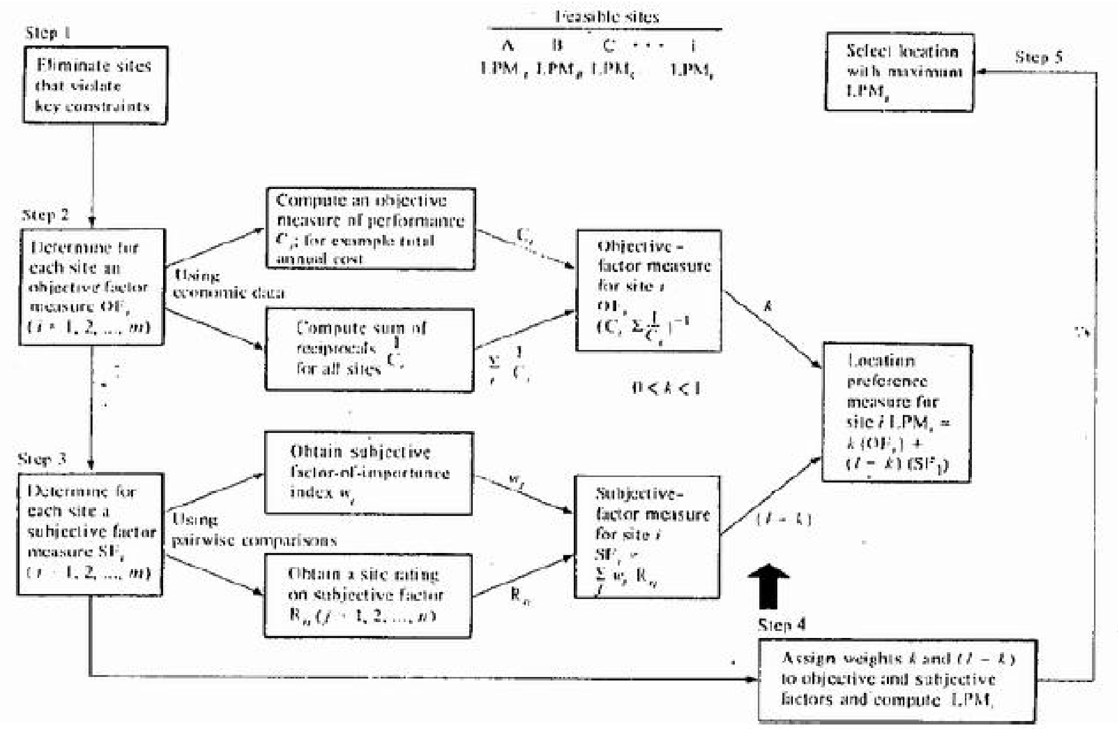
Suppose that after stage 2 we have identified three alternative sites for a. new plant location. We wish to develop for each site a measure of preference that combines both objective and subjective factors. For this purpose we might use the method for evaluating alternative product designs. A versatile approach especially designed for the location-selection problem is a model developed by Brown and Gibson; its key features are displayed in Fig. 6. In applying the Brown-Gibson approach, outlined in Fig. 6, we go through the following sequence of steps:

1. Eliminate any site that does not meet certain basic requirements. This may be a technical requirement, e.g., the availability of abundant cheap electricity for an aluminum plant, or a budget constraint for the purchase of the site.
2. Compute an objective-factor measure of performance OF_i for each site. Usually we estimate all relevant costs to compute the total annual cost for each site C_i. Next we determine the objective-factor measure OF_i by multiplying C_i, by the sum of the reciprocal site costs $\sum (1/C_i)$ and taking the reciprocal.
3. Determine key subjective factors and estimate their subjective-factor measure SF, for each site by
   a. Deriving a factor rating w_j for each subjective factor ($j = 1, 2,..., n$) using a forced-choice pairwise comparison procedure. Accordingly, one factor is selected over another, or they are rated equal.
   b. Ranking each site for each subjective factor separately R_{ij} ($0 \le R_{ij} \le 1$, $\sum R_{ij}=1$).
   c. Combining for each site the factor rating and site ranking, $SF_i = w_1R_{i1} + w_2R_{i2} + \ldots + w_nR_{in}$
4. Combine for each site the objective-factor measure OF_i and subjective-factor measure SF_i by assigning weights k and $1 - k$ respectively, to obtain a *location preference measure* (LPM), i.e.,

   $$LPM_i = k(OF_i) + (1-k)(SF_i) \quad 0 < k < 1$$

   If the site selection is going to be based entirely on costs, $k = 1.0$ and the subjective-factors are ignored. If objective factors ore going to count 4 times as much as the subjective ones, then $k = .8$ ($.8/.2 = 4$), etc. The preference measure for a given site can be tested under different assumptions concerning costs and the importance of various subjective factors.

5. Select the site with the maximum LPM.



This procedure will be illustrated with an example. Note, however, that it is quite general in nature and can be used not only for site selection but also for many complex decision problems where it is necessary to combine subjective and objective, factors into an overall measure of preference for each alternative. The Brown-Gibson method would be equally suitable for the evaluation of alternative product designs, processes, or layouts of facilities, to name a few potential applications.

Example 5

Miranda Pacific, Inc., a pulp and paper company, has just completed a feasibility study (Phase one) for the construction of a new plant to cover future increases in demand, as evidenced by a steady upward trend during recent years. The study has concluded that the expected increase in demand justifies the minimum economic plant size needed for a paper mill, since capacity changes for this industry can be made only in large increments.

In stage 1 of phase two the study of market changes and pulp and paper manufacturing characteristics for different geographic regions has shown that the most suitable region for a new plant is the Pacific Northwest (Idaho, Oregon, Washington) because of its proximity to the raw material (wood chips converted into paper pulp and then various types of paper) and good transportation networks (waterways and rail and highway systems).

In stages 2 and 3 for the selection of the best area and sites, a detailed analysis of requirements has indicated that four sites along the Columbia River would be satisfactory in terms of the large quantities of water required for pulp and paper processing. Let us call these sites A. B. C, and D near different towns along the river. The application of the Brown- Gibson approach for this case is illustrated below.

Step 1 Site D is eliminated early because real estate in that area is prohibitively expensive and the sum needed to purchase the required number of acres exceeds the amount allowed in the capital budget.
Step 2 In the remaining sites all annual costs for production inputs (raw materials. energy, etc.) are the same except for labor, distribution, and taxes:

Annual costs (million)						
Site *I*	Labor	Distribution	Taxes	All others	Total C_i	Reciprocal $1/C_i$
A	$3.62	$ 2.08	$ .25	$4.00	$9.95	.100503
B	3.40	2.75	.30	4.00	10.45	.095694
C	3.75	2.90	.40	4.00	11.05	.090498
						.286695

The objective rating factor for each site is obtained by substitution in the formula

$$OF_i = [\, C_i \sum (1/C_i)\,]^{-1} \quad \text{so that} \sum_i (OF_i) = 1$$

Thus, the objective factors for alternative sites are

$$OF_A = [(9.95)(.2867)]^{-1} = .35056$$
$$OF_B = [(10.45)(.2867)]^{-1} = .33378$$
$$OF_C = [(11.05)(.2867)]^{-1} = .31566$$

Step 3 With climate, recreation opportunities, city services, and labor being the same in all areas, the key subjective factors in the selection of a site have been identified as (1) housing, (2) education, and (3) community attitudes.

These must now be evaluated using a *forced-choice procedure*, which compares each factor with the others by considering one pair at a time. Repetitive application of the forced-choice procedure yields two results: (1) we obtain a subjective factor importance index w_j, which simply measures the relative weight given to each .subjective factor, and (2) for each subjective factor separately we obtain a ranking of each site R_{ij}.
Suppose that the special group assigned to select a site responded to paired comparisons as follows:
1. Education (1) versus housing (2): both judged equally important
2. Education (1) versus community attitudes (3): choose community attitudes as more important

3. Housing (2) versus community attitudes (3): choose community attitudes
This information can be summarized in a table in which we can compute the subjective- factor importance index w_j:

Factor j	Pairwise comparisons 1	2	3	Sum of preferences	Relative importance Index w_j
Education (1)	1	0		1	¼ = .25
Housing (2)	1		0	1	¼ = .25
Community Attitudes (3)		1	1	2	½ = .50
TOTAL				**4**	**1.00**

In the column for each pairwise comparison possible we assign 1 to the factor preferred and 0 to the other, while for the case of equivalence both factors are assigned a value of 1. It is important in using such a procedure to check preferences for consistency. Thus, if factor 1 is preferred to 2 and 2 is preferred to 3, 1 must be preferred to 3; otherwise the responses are inconsistent.

Next, for each subjective factor separately we repeat the same pairwise comparisons with sites to determine their relative ranking R_{ij}. For the sites considered by Miranda Pacific, Inc., the results of this procedure are shown in the following table.

Education (factor 1)				
Pairwise Comparison response				
Site i	1	2	3	Site Ranking R_{i1}
A	1	1		.50
B	0		1	.25
C		0	1	.25
Total				1.00

Housing (factor 2)				
Pairwise Comparison response				
Site i	1	2	3	Site Ranking R_{i2}
A	0	1		.25
B	1		1	.50
C		1	0	.25
Total				1.00

Community attitudes (factor 3)				
Pairwise Comparison response				
Site i	1	2	3	Site Ranking R_{i3}
A	0	0		.00
B	1		0	.33
C		1	1	.67
Total				1.00

Summary of subjective factors evaluation				
Site Rating R_{ij}				
Factor j	A	B	C	Relative importance index w_j
1	.50	.25	.25	.25
2	.25	.50	.25	.25
3	0	.33	.67	.50
Total				1.00

To determine the subjective factor measure for a site SF_i we must multiply the site rating for a given factor R_{ij} by the relative importance index w_j of that factor and sum over all the subjective factors included in the analysis

$$SF_i = R_{i1}w_1 + R_{i2}w_2 + \ldots + R_{in}w_n = \sum_{j=1}^{n} R_{ij}w_j$$

In our example the subjective rating factors for alternative sites are

$$SF_A = (.50)(.25) + (.25)(.25) + (0)(.50) = .1875$$
$$SF_B = (.25)(.25) + (.50)(.25) + (.33)(.50) = .3525$$
$$SF_C = (.25)(.25) + (.25)(.25) + (.67)(.50) = .4600$$

Step 4 Having completed the evaluation of both objective and subjective location factors, we can now proceed to combine the results and determine an overall location-preference measure LPM, for each site. This synthesis requires a crucial decision, the weight that will be assigned to each category of factors. If the weight given to the objective factors is k ($0<k<1$), the subjective factors receive a weight $1 - k$. Thus, for a given site we have

$$LPM_i = k(OF_i) + (1-k)(SF_i)$$

For our example, management considers the weight of objective factors 4 times as important as that of subjective ones; that is, $k = 4(1 - k)$. This is true when $k = .8$. The location-preference-measure values for the sites considered will be

$$LPM_A = (.8)(.35056) + (.2)(.1875) = .3179$$
$$LPM_B = (.8)(.33378) + (.2)(.3525) = .3375$$
$$LPM_C = (.8)(.31566) + (.2)(.4600) = \underline{.3446} \text{ (preferred location site)}$$
$$1.0000$$

Step 5 According to the Brown-Gibson approach, Miranda, Inc., must choose site C, since this receives the highest value for a location measure. We note that even though it is the least attractive alternative based on objective factors, its superiority in subjective-factor rating puts it at the top, despite a high weight value for cost factors. The sensitivity of the preference-location measures for each site with respect to the weight assigned to objective and subjective factors can be shown with the following diagram. For our example, only for a value of k near 1.0, for which subjective factors are essentially ignored, does the choice switch to site A (*A potential weakness of the Brown-Gibson approach is in the use of pairwise comparisons. These may oversimplify a choice by failing to reveal the strength of a staled preference).*

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