Plant location : a quantified model for community and plant site selection
by Phillip Argene Brown

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Industrial and Management Engineering
Montana State University

Abstract:
The problem of determining where to locate new plants is usually-divided into two stages: (1) selecting the region and (2) selecting the community and plant site. The objective of this study is to reapply current location theory on the basis of least-total-cost-site by developing a general model using consistent quantification techniques for selecting the community and plant site.

A model, describing the location measure of a potential site for a hypothetical plant, is defined in terms of critical, objective, and subjective location factors. Its applicability is tested, with the aid of a computer, by calculating location measures of six potential sites in Montana.

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Date August 7, 1970

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Phillip Argene Brown

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ABSTRACT

The problem of determining where to locate new plants is usually divided into two stages: (1) selecting the region and (2) selecting the community and plant site. The objective of this study is to reapply current location theory on the basis of least-total-cost-site by developing a general model using consistent quantification techniques for selecting the community and plant site.

A model, describing the location measure of a potential site for a hypothetical plant, is defined in terms of critical, objective, and subjective location factors. Its applicability is tested, with the aid of a computer, by calculating location measures of six potential sites in Montana.

Chapter I.

INTRODUCTION

Importance of Plant Location

Economic changes over the past 70 years have reduced the margin between unit selling price and unit cost for many industries. With the unit selling price usually fixed by competition, an increase in gross profit requires either an increase in sales or a reduction in unit cost. In either case, one limiting factor in increasing profit is the location of the plant. [6], [16], [18]

Another reason for new emphasis on plant location is that a mistake in plant location can be costly to correct. Once the location has been selected, the overall efficiency and effectiveness of the plant are limited to some extent and may preclude the possibility of a profitable operation. Increasing the profitability of the operation can depend on transferring the new facility to another site at tremendous cost.

History of Location Theory

According to Holmes [6], Reed [16], and Yaseen [26], existing plant location theories do not provide satisfactory solutions to the location problem. One reason for this lack of progress is the nature of the factors that should be considered in determining the best location. Many of these factors do not lend themselves to quantitative measurement. For this reason most plant location authors have confined their analyses to monetary factors. Non-monetary factors are usually defined but their application is left to the reader. Yaseen [26, p.1] recognized this void in plant location theory when he stated: "No scientific advances, unfortunately, can be claimed in the determination of where new plants should be built."

The analysis of the plant location problem has generally been based on one of the following concepts: least-production-cost-site, maximum-profit-site, least-distribution-cost-site, or least-total-cost-site.

Most of the early work in location theory was concerned with determining the least-production-cost-site. This concept includes only those factors which directly affect the cost of production. Outstanding contributors to this concept were two Germans, Johann von Thunen [5] and Alfred Weber [25] and an American, Edgar Hoover [8]. Von Thunen's theory assumes that the location is given, the land surface is homogeneous, and the type of industry is to be determined. The complete analysis is based on two concepts: the theory of rent [1] and the cost of transportation. The industry which has the minimum sum of rent and transportation costs is selected.

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[1]Weber [25] theorizes that land rents reflect advantages due to favorable locations of industry in relation to raw material deposits and market areas.

In contrast to von Thunen's work, Weber developed a theory based on the assumptions that the branch of industry is known and that the exact location is sought. In addition to the cost of transportation, Weber includes the cost of labor and agglomerating forces[2] as the principal factors in plant location. He divides the problem into two stages: (1) selection of the region, and (2) selection of the location. Transportation and labor costs are designated as regional factors, while agglomerating forces are considered to be local factors. Melvin Greenhut [5, p. 255] summarized Weber's theory as follows:

> The cost of transfer tends to draw industry to the site of least transfer expense, while the cost of labor may cause displacement of that site to a place where the savings in labor cost are larger than the additional transportation costs. The decentralizing tendencies of these two factors are counteracted or intensified by Weber's third consideration: the agglomerating force (marketing advantages, proximity to auxiliary industries, economics of scale) and its corollary, the deglomerating influence (land rent). These considerations draw industry closer together or disperse it, depending upon the respective strength of each force.

Edgar Hoover's location theory [8], which also considers cost factors, is characterized by the inclusion of demand factors. He divides the activities of a productive enterprise into three stages:

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[2]Reed [16, p. 5] defines agglomerating and deglomerating forces as: "Agglomerating forces are those forces which tend to cause industry to gather densely in limited areas: the factors or forces favoring urban location. Deglomerating forces are those forces which tend to cause industry to scatter or to seek locations away from other industry: the factors or forces favoring rural location."

1. Procurement: Purchasing and bringing the necessary materials and supplies to the site of processing.
2. Processing: Transforming the materials into more valuable forms (products).
3. Distribution: Selling and delivering the products.

Procurement and processing are cost factors and distribution is the demand factor.

Hoover states that he is not concerned with the analysis of the problem per se, but is interested instead in the formulation of principles. His major contributions to location theory are: (1) discussions of the influence of location factors, (2) recognition of the error in assuming transportation costs are proportional to distance, and (3) recognition of capitalistic influences on location.

In 1956 Melvin Greenhut [5] introduced a location theory based on the concept of the maximum-profit-site. He defines the maximum-profit-site as: "the site at which the spread between total receipts and total cost is the greatest." His mathematical description [5, pp. 286-287] of a general theory is:

$$L = f(R-C) \qquad (1-1)$$

$$C = f(SR \times C_a) \qquad (1-2)$$

$$R = f(SR \times m) \qquad (1-3)$$

L stands for location, C for total cost, R for total revenues, and SR for sales radius.[3] C_a represents the average cost (per unit), exclusive of freight, and m stands for the profit maximizing net-mill price.[4] [Footnotes mine]

Greenhut proposes that if for each firm within an industry:

1. $m \neq C_a$, and $\Delta R = \Delta C$, a state of location unequilibrium exists, or
2. $m = C_a$, and $\Delta R = \Delta C$, there is location equilibrium.

He finalizes his proposal with a hypothesis that new locations or relocations will cause a movement toward equilibrium conditions.

Most of the recent work in location theory is founded on a concept of either least-distribution-cost-site or least-total-cost-site. A least-distribution-cost concept is usually based on "decision data related to delivered cost to customer" [16, p. 3], such as minimizing service times or distances to customers. Two characteristics of location theories utilizing a least production cost concept are:

1. They seldom include more than time and distance factors in their analysis, and
2. They primarily utilize analytical models such as linear programming.

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[3]According to Greenhut [5], sales radius is defined as the total volume of unit purchases which produce the greatest possible profit.

[4]According to Greenhut [5], profit maximizing net-mill price is defined as the average revenue (per unit) which, excluding freight, maximizes the total profit.

Reed [16, pp. 26-27] analyzed location theories founded on a criterion of least distribution cost as follows:

> Most of the pure quantitative work which has been done relative to location studies has used some form of the transportation or assignment methods of linear programming. These in general, however, have been solutions to the problem of assigning "n" plants to "n" locations. The problem in this case is not one of selecting a location. The decision as to which locations are to be considered in the model has been determined prior to the model formulation.

With regard to the use of analytical models in plant location in the future, Reed [16, p. 27] states:

> The procedure may offer possibilities for long-range planning where several locations have been purchased and the question of when to use individual locations and what to produce at that location must be decided.

Most of the literature on plant location theory is based on a concept of least-total-cost-site. [1], [12], [16], [26] In general, the criterion is an extension of the least-production-cost-site criterion. In addition to factors affecting production cost, factors affecting the overall operation are also included in the analysis. A distinguishing characteristic of this criterion is that decision data are related to all factors that might affect a plant's operation.

Reed, [16, p. 1] has defined the location problem in terms of least-total-cost-site as:

> ... the determination of that location which, when considering all factors, will provide minimum delivered to customer costs[5] of the product(s) to be manufactured. [Footnote mine]

The analysis of the location problem using a concept of least total cost is usually divided into two stages: (1) selection of the general territory or region, and (2) selection of the community and plant site. In selecting the region, information of a more general nature is required, whereas the selection of the community requires information regarding specific costs, attitudes, etc. A general list of the factors affecting regional and community selections is presented in Table 1-1. [12, p. 39]

Table 1-1. General location factors to be considered in a typical location problem.

Location Factor	Regional Selection	Selection of Site & Community
Market	*	
Raw Materials	*	
Transportation	*	*
Power	*	*
Climate & Fuel	*	
Labor & Wages	*	*
Laws & Taxation	*	*
Community Services & Attitude		*
Water & Waste		*

[5]Holmes [6] has defined delivered to customer cost as: "... the total of all costs which a commodity must bear from the time it is taken from nature until it is delivered to the manufacturer's customer."

A regional analysis is usually based on a cost evaluation of the regional factors shown in Table 1-1. That region which minimizes the sum of the costs of the regional factors is then selected.

The procedure[6] used in selecting the community and plant site is:

1. Assigning a weight to each factor
2. Ranking locations for each factor
3. Distributing the factor weights among their respective set of ranked locations
4. Summing the location weights for each location, and
5. Selecting that site with the maximum sum of location weights.

The four previously mentioned location concepts will not be applied because: (1) required input data is unavailable, (2) assumptions are not practical for real world problems, (3) quantitative measures for subjective location factors are inconsistent, or (4) objectives of management are variable. [12], [16], [26]

According to Reed [16], rather than apply existing location theory, an industry or firm normally: (1) designs or assumes a general approach to the problem, (2) establishes an incomplete set of factors affecting selection, (3) evaluates the factors, and (4) makes a decision based upon available data.

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[6]For a thorough discussion on the detailed procedure, see Reed. [16, pp. 19-21]

Chapter II.

DEVELOPMENT OF LOCATION MODEL

The strongest criticism of current location theory derived from the least-total-cost-site concept is that the quantitative methods used to evaluate community and site factors are inconsistent. As an example, personal whims are often allowed to overshadow important cost factors. [6], [16], [26].

The method employed in current theories for selecting the region, as defined in Chapter I, has received a more encouraging response. [16] A prime reason for this response is that all of the factors considered in selecting a region are monetary factors. [12] Therefore, with an acceptable method available for selecting the region, emphasis in this study will be placed on selecting the community and the plant site.

Objective of Study

The objective of this study is to reapply current location theory on the basis of least-total-cost-site by developing a general model using consistent quantification techniques for selecting the community and plant site. This objective is accomplished in four steps:

1. Classifying the location factors[7]

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[7]Community and plant site factors will be referred to as location factors from here on.

2. Defining a general model in terms of the classifications.

3. Quantifying the terms of the general model, and

4. Formulating the final model.

An example, illustrating the application of the model, is presented in Chapter III and a critique of the model is presented in Chapter IV.

Classification of Location Factors

There are numerous lists of factors available for use in plant location analyses. [1], [12], [16], [18] In addition, most authors present a list of subfactors for each main factor. For example, some of the subfactors for the main factor, "availability of transportation", are: (1) airline service, (2) trucking service, and (3) train service.

Development of the location model in this study is not based on the discovery of a new list of main factors or subfactors. It is however, characterized by the recognition of three classifications of location factors. Main factors and subfactors in all of the previously cited lists can be divided into: (1) critical factors, (2) objective factors, and (3) subjective factors.

A main factor is classified as critical if one or more of its subfactors precludes the location of a plant at a particular site regardless of other conditions that might exist at the site. For instance, an industry that uses a large amount of water would certainly not consider a site with possible shortages of water. In most cases critical factors cause a reduction in the number of sites to be considered in a location study. For this reason they should be considered first.

Objective factors are those factors which can be classified in terms of cost with little or no personal bias. They also contribute directly to operational costs and can be classified as critical factors. Examples of objective factors are labor, raw material, and transportation costs.

The third classification, subjective factors, is usually characterized by the impossibility for monetary measurement. For instance, community attitude is a subjective factor because it can seldom be given a dollar value. Some factors can be classified as both critical and subjective.

Table 2-1 represents a typical list of location factors by classification.

Table 2-1. Plant Location Factors

Critical Factors
Availability of Labor
Availability of Utilities
Community Attitude
Availability of Transportation

Table 2-1. Continued.

Objective Factors
Cost of Transporting Raw Materials
Cost of Transporting Finished Products
Cost of Utilities
Cost of Labor
Cost of Building
Cost of Taxes
Subjective Factors
Availability of Transportation
Industrial Sites - cost, size, location, etc.
Climate
Educational Facilities
Union Activity
Recreation Facilities and Opportunities
Housing - availability & condition of
Future Growth - opportunities for
Community Services
Employee Transportation Facilities
Cost of Living
Competition
Complementary Industries
Availability of Labor
Community Attitude

Definition of General Model

The general model is based directly upon the above classifications. That is, the location measure (or potential) for each site, LM, is a combination of three values: (1) critical factor measure, (2) objective factor measure, and (3) subjective factor measure.

The model which determines the location measure for site "i" (LM_i) is defined as follows:

$$LM_i = CFM_i \cdot [X \cdot OFM_i + (1-X) \cdot SFM_i] \qquad (2\text{-}1)$$

where:

1. CFM_i is the combined measure of the critical factors for site "i" (CFM_i = 0 or 1)
2. OFM_i is the combined measure of the objective factors for site "i" ($0 \leq OFM_i \leq 1$, and $\sum_i OFM_i = 1$)
3. SFM_i is the combined measure of the subjective factors for site "i" ($0 \leq SFM_i \leq 1$, and $\sum_i SFM_i = 1$), and
4. X is the objective factor decision weight ($0 \leq X \leq 1$).

That site which receives the largest location measure, as defined in Equation 2-1, is then selected.

Quantification of Location Measures

To determine the location measure of a site, there are four terms in Equation 2-1 that must be evaluated: (1) critical factor measure, (2) objective factor measure, (3) subjective factor measure, and (4) the value of the objective factor decision weight. This section will be devoted to quantifying these four measures.

Quantification of critical factor measure. The critical factor measure, in terms of the individual critical factors, is defined as:

$$CFM_i = \prod_j CFI_{ij}$$

where CFI_{ij} is defined as the critical factor index for site "i" and critical factor "j".

For each critical factor there is only one decision to be made for each site, "Does the site have the minimum requirement of the critical factor?" If the answer is yes, the value of the critical factor is one, indicating that on the basis of this critical factor the site does have a location measure. On the other hand if the answer is no, the critical factor index is zero indicating that the site should be excluded from further consideration since its location measure is zero. Therefore, if a site is to receive a location measure, LM, the critical factor indexes for that site must all equal one.

<u>Quantification of objective factor measure</u>. By definition, all objective factors can be measured in monetary units. However, in order to insure compatibility between objective and subjective factor measures, objective factor costs are converted to dimensionless indexes.

The objective factor measure for site "i", in terms of the objective factor costs, is defined as:

$$OFM_i = [OFC_i \cdot (\sum_i (1/OFC_i))]^{-1} \qquad (2\text{-}3)$$

where OFC_i is the total objective factor cost for site "i".

Development of Equation 2-3 is based on three restrictions:

1. The site with the minimum cost must have the maximum measure
2. The relationship of the total objective factor cost for each site as compared to all other sites must be preserved, and
3. The sum of the objective factor measures must equal one.

Restrictions 1 and 3 are imposed to insure that the objective factor measure will be compatible with the subjective factor measure.

The implication of restriction 2 is that a site with one-half the objective factor cost of another is assigned twice the objective factor measure of the other site.[8] Equation 2-4 defines this implication for any two sites "i" and "j":

$$OFM_i \cdot OFC_i = OFM_j \cdot OFC_j \qquad (2\text{-}4)$$

Based on the preceding three restrictions and assuming a total of "n" sites, the development of Equation 2-3 is as follows:

1. Imposing restrictions (1) and (2) and applying Equation 2-4 (for j = 1,2,...,i-1,i+1,...,n) results in the following set of n-1 equations:

$$OFM_1 \cdot OFC_1 = OFM_2 \cdot OFC_2 = \ldots\ldots = OFM_i \cdot OFC_i = \ldots$$
$$\ldots = OFM_n \cdot OFC_n \qquad (2\text{-}5)$$

[8]The inverse relationship is due to restriction 1.

2. Writing restriction (3) in its mathematical form results in:

$$OFM_1 + OFM_2 + \ldots + OFM_i + \ldots + OFM_n = 1 \qquad (2\text{-}6)$$

3. Combining the set of equations represented by Equation 2-5 and substituting in Equation 2-6 results in:

$$(OFC_i/OFC_1 + OFC_i/OFC_2 + \ldots + OFC_i/OFC_n)\cdot OFM_i = 1 \qquad (2\text{-}7)$$

4. Equation 2-7 can now be simplified to the form of Equation 2-3.

<u>Quantification of subjective factor measure</u>. The subjective factor measure for site "i" is influenced by two quantitites: (1) the relative weight of each subjective factor,and (2) the weight of site "i" relative to all sites for each of the subjective factors. Mathematically the subjective factor measure for site "i" is defined as:

$$SFM_i = \sum_i (SFW_k \cdot SW_{ik}) \qquad (2\text{-}8)$$

where:

1. SFW_k is the weight of subjective factor "k" relative to all subjective factors, and
2. SW_{ik} is the weight of site "i" relative to all potential sites for subjective factor "k".

Values of the subjective factor weight, SFW, and site weight, SW, are determined with the aid of a subjective quantification technique referred to as preference theory. [4]

Preference theory is a tool used to assign weights to subjective properties[9] in a consistent and systematic manner. For each decision (which is a comparison between two factors) there are three possible results: (1) the first property is preferred over (more important than) the second, (2) the second property is preferred over (more important than) the first, or (3) neither property is preferred, i.e., the decision maker is indifferent. The corresponding numerical values for each of the above results are: (1) "1" for the first property and "0" for the second, (2) "1" for the second property and "0" for the first, and (3) "0" for both properties. Each of the properties are then compared two at a time, recording the appropriate values beside the properties, until all possible combinations have been exhausted.[10]

For ease of comparison a preference matrix is usually constructed. Table 2-2 is an illustration of such a matrix for four properties. The first decision (Table 2-2) is to compare the importance of property 1 to that of property 2. P_1 and P_2 are preference values of 0 or 1,

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[9]Properties are referred to in preference theory as alternatives, elements, factors, components, etc.

[10]The total number of decisions to be made for a problem involving "n" properties is: $n!/[2!(n-2)!]$.

based on this decision. Next, properties 1 and 3 are compared, then 1 and 4, etc. until the final decision of comparing properties 3 and 4 is made.

Table 2-2. General preference matrix for four properties

	Decision					
Property	1	2	3	4	5	6
1	P_1	P_3	P_5			
2	P_2			P_7	P_9	
3		P_4		P_8		P_{11}
4			P_6		P_{10}	P_{12}

Once the preference values have been assigned, the next step is to calculate the property weight as illustrated in Table 2-3.

Table 2-3. General preference matrix with property weights for four factors

Property	Decision 1	2	3	4	5	6	Sum of Preference Values	Property Weight
1	P_1	P_3	P_5				$P_1+P_3+P_5$	$(P_1+P_3+P_5)/P$
2	P_2			P_7	P_9		$P_2+P_7+P_9$	$(P_2+P_7+P_9)/P$
3		P_4		P_8		P_{11}	$P_4+P_8+P_{11}$	$(P_4+P_8+P_{11})/P$
4			P_6		P_{10}	P_{12}	$P_6+P_{10}+P_{12}$	$(P_6+P_{10}+P_{12})/P$
Total							P	1

The property weight is the ratio of the number of times a factor was preferred to the total number of preferred decisions. The ratio is a measure of the relative importance of each property compared to all properties.

Values of the subjective factor weight and the site weight may now be determined with the direct application of preference theory. The procedures for calculating these values are:

1. Properties - Subjective Factors (constant for all sites)
   a. Define a list of subjective factors.
   b. Based on past experience or company policy, construct a preference matrix for the subjective factors.
   c. Calculate the subjective factor weight (SFW_k) from the preference matrix in part b.

2. Properties - Potential Sites

For each subjective factor "k":

a. Gather data concerning the subjective factor in question for each site.

b. Based on the research in part a., construct a preference matrix for the potential sites and the subjective factor in question.

c. Calculate the site weights (SW_{ik}) from the preference matrix in part b.

Quantification of objective factor decision weight. The objective factor decision weight, X, is defined as the measure of the relative importance of the objective factor classification of the entire location problem.[11] The value of the objective factor decision weight is based on a judgment decision by top level management of the locating plant. A decision of this nature is usually based on company policy or past experience, or both, which are subject to error. Therefore, the sensitivity of the location measures to changes in the objective factor decision weight should be investigated.

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[11] Defining the weight of the location problem to be based on objective factors automatically defines the subjective factor decision weight (1-X) since the range on X is: $0 \leq X \leq 1$.

Formulation of Final Model

The model which defines the location measure for site "i" (LM_i) can now be redefined in terms of the preceding factors as:

$$LM_i = [\prod_j CFI_{ij}] \, [(X \cdot OFC_i \cdot \sum_i 1/OFC_i)^{-1} +$$

$$(1-X) \cdot \sum_k SFW_k \cdot SW_{ik}] \qquad (2-9)$$

where:

1. CFI_{ij} if the critical factor index for site "i" and critical factor
2. OFC_i is the total objective factor cost for site "i"
3. SFW_k is the weight of subjective factor "k" relative to all subjective factors
4. SW_{ik} is the weight of site "i" relative to all potential sites for subjective factor "k", and
5. X is the objective factor decision weight.

That site which receives the largest location measure, as defined by Equation 2-9 is then selected.

Chapter III.

APPLICATION OF PLANT LOCATION MODEL

Procedure for Selecting Best Location

The complete procedure for determining the best location for a plant can be divided into three phases:

1. Defining information necessary to compare potential sites
2. Collecting the information for each site defined in phase 1, and
3. Evaluating potential sites on the basis of information collected in phase 2 and the location model defined in Chapter II.

Phase 1 entails defining a list of location factors and subfactors by classification which can then be used to evaluate potential sites. As stated in Chapter II, there are many such lists available to aid a location analyst in this phase of location theory. Appendix A illustrates a list of factors and subfactors which can be used to evaluate potential sites.

Consulting government and local data collection agencies may reduce the time required in phase 2. However, past experience indicates that location data are frequently unavailable or inconsistent with respect to time, source, and description. In most cases the location analyst will be forced to gather data at each potential site. A typical set of data for a hypothetical plant and six cities (sites) in Montana is displayed in Appendix A.

Upon completion of phases 1 and 2, each potential site should be evaluated in terms of the critical factors defined in phase 1. All sites that meet the minimum requirements for these critical factors are then evaluated according to Equation 3-1, which is a reduction of Equation 2-9.[12]

$$LM_i = X \cdot OFM_i + (1-X) \cdot SFM_i \quad (3\text{-}1)$$

Example Problem[13]

To illustrate the application of the location model presented in Chapter II, consider the problem of locating a plant in one of six cities. Appendix A displays the results of the first two phases of the procedure outlined above. Since the six cities defined in Appendix A have all met the minimum requirements of the critical factors, the remainder of the problem may be divided into five steps:

1. Evaluating objective factor measures for each site
2. Evaluating subjective factor measures for each site
3. Evaluating location measures for each site

---

[12] The notation for the critical factor measure (CFM_i) has been replaced with its numerical value, "1".

[13] The following example problem was solved with the aid of a computer. A detailed documentation and listing of the computer program is provided in Appendix D.

4. Investigating the sensitivity of location measures to changes in X, and

5. Investigating the sensitivity of location measures to changes in input data.

Evaluating objective factor measures for each site. The objective factor measure for any site "i", OFM_i, was defined in Chapter II, Equation 2-3 as:

$$OFM_i = [OFC_i \cdot (\sum_i 1/OFC_i)]^{-1} \qquad (3-2)$$

where OFC_i is the total objective factor cost for site "i". Determination of the total objective factor cost for any site "i" in this example problem requires six individual costs:[14] (1) raw material, (2) finished product, (3) utilities, (4) labor, (5) building, and (6) taxes.

The basic cost of raw material is the same at all three sources (Appendix A, Table A-3) and only the cost of transporting the raw material to each site was considered. Furthermore, it was assumed that any one of the three sources could satisfy the raw material requirements for the locating plant. Therefore, the cost of raw materials for site "i" is:

$$CRM_i = \min_j [TRC_{ij}] \qquad (3-3)$$

---

[14] All objective costs are evaluated on a monthly basis.

where:

1. CRM_i is the cost of raw materials at each site "i", and

2. TRC_{ij} is the raw material transportation cost from source "j" to site "i".

Transportation costs for each site "i" and source "j" are defined according to M. D. Ray's [15] transportation cost equation[15] as:

$$TRC_{ij} = aX_{ij}^{b}Y_{ij}^{c} \quad (3\text{-}4)$$

where:

1. X_{ij} is the distance to "i" from "j"

2. Y_{ij} is the weight of raw materials shipped to "i" from "j", and

3. a, b, and c are constants to be determined by a multiple regression analysis.[11]

Values of X_{ij} and Y_{ij} are shown in Appendix A, Tables A-3 and A-4. The empirical data for the regression analysis is shown in Appendix A, Table A-5. Table 3-1 shows the resulting raw material costs for each site.

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[15]Ray's [15] equation was selected on the basis of his extensive empirical study relating to transportation cost equations.

Table 3-1. Raw material sources and costs for each site

Site	Source of Raw Material	Cost of Raw Material
1	3	$ 1,079
2	2	$ 945
3	1	$ 490
4	1	$ 979
5	2	$ 925
6	3	$ 1,507

For example, the cost of raw materials at site 1 for each of the three sources of raw material is:

$$TRC_{11} = (.003567)(256)^{.509}(200{,}000)^{.8319} = \$\ 1{,}542$$

$$TRC_{12} = (.003567)(224)^{.509}(200{,}000)^{.8319} = \$\ 1{,}440$$

$$TRC_{13} = (.003567)(127)^{.509}(200{,}000)^{.8319} = \$\ 1{,}079$$

The raw material cost for site 1, as defined by Equation 3-3, is then $1,079.

Finished product costs for each site are based only on the cost of transporting the finished products to the markets according to M. D. Ray's [15] transportation cost equation:

$$MC_i = \sum_j aX_{ij}^b \, Y_{ij}^c \qquad (3\text{-}5)$$

where:

1. X_{ij} is the distance from site "i" to market "j",
2. Y_{ij} is the weight of finished product to be shipped from site "i" to market "j", and
3. a, b, and c are constants to be determined using a multiple regression analysis.

The values of X_{ij} and Y_{ij} and the empirical data for a regression analysis to determine the constants a, b, and c are listed in Appendix A, Tables A-6 through A-9. Table 3-2 shows the resulting finished product costs for each site. For example, the cost of transporting the finished products from site 1 to the 18 markets is:

1. $MC_1 = a(256)^b(334)^c + a(0)^b(44{,}516)^c + a(142)^b(4{,}056)^c + \ldots$

   $\ldots + a(308)^b(2{,}399)^c + a(280)^b(2{,}590)^c$
2. a = .003567, b = .509, and c = .8319
3. MC_1 = \$ 1,316

Table 3-2. Marketing (finished product) costs for each site

Site	Marketing Cost
1	\$ 1,316
2	\$ 1,485
3	\$ 1,467
4	\$ 1,600
5	\$ 1,263
6	\$ 1,950

All remaining costs (utilities, labor, building, and taxes) are calculated directly from the information in Appendix A, Tables A-10 through A-19. Table 3-3 shows these costs for each site.

Table 3-3. Cost of utilities, labor, building, and taxes for each site

	Cost ($)			
Site	Utilities	Labor	Building	Taxes
1	9,460	12,773	514	3,095
2	11,563	11,249	563	3,470
3	12,768	10,422	539	3,580
4	10,548	12,159	490	3,755
5	10,898	12,333	612	3,701
6	11,628	12,244	612	3,393

For example, the costs in Table 3-3 for site 1 are calculated as follows:

1. Utility Cost (i) = Gas Cost (i) + Water & Sewage Cost (i)

   a. Gas Cost (i) = $\sum_j A_{ij} B_j$

      where:

      i. A_{ij} is the gas rate at site "i" for gas category "j", and

      ii. B_j is the amount of gas in category "j".

b. Water & Sewage Cost (i) = $\sum_j C_{ij} D_j$

where:

i. C_{ij} is the water and sewage rate at site "i" for water and sewage category "j", and

ii. D_j is the amount of water and sewage in category "j".

c. Therefore, the Utility Cost for site 1 is:

Gas Cost (1) = (.33)(1)+(.33)(99)+(.33)(200)+ (.33)(700)+(.33)(19,000)

= $ 6,600.

Water & Sewage Cost (1) = (.33)(1,000)+(.19)(1,000)+ (.13)(18,000)

= $ 2,860.

Utility Cost (1) = $ 9,460.

2. Labor Cost (i) = $\sum_j E_j F_{ij} X + \sum_k G_k H_{ik}$

where:

a. E_j is the required number of type "j" hourly paid employees

b. F_{ij} is the hourly wage rate for type "j" employees at site "i"

c. X is the average monthly working hours

d. G_k is the required number of type "k" monthly paid employees, and

e. H_{ik} is the monthly salary for type "k" employees at site "i".

Therefore, at site 1

$$\text{Labor Cost }(1) = [(12)(1.75)+(12)(2.50)]\ [173] + (4)(750) + (1)(950)$$

$$= \$\ 12{,}773.$$

3. $\text{Building Cost }(i) = CRF/12\ [\sum_j W_{ij} S_j]$

where:

a. CRF is the capital recovery factor for a period of 20 years and an interest rate of 10%

b. W_{ij} is the cost per square foot at site "i" for floor level "j", and

c. S_j is the total square footage of floor level "j".

Therefore, at site 1

$$\text{Building Cost }(1) = .1175/12\ [(6)(2500)+(15)(2500)]$$

$$= \$\ 514.$$

4. $\text{Tax Cost }(i) = (V)\ (M_i)\ (T)/12$

where:

a. V is the value of the property

b. M_i is the mill levy at site "i", and

c. T is the percent of property value that is taxable.

Therefore, at site 1

$$\text{Tax Cost (1)} = (500{,}000)(.18569)(.40)/12$$
$$= \$\ 3{,}095.$$

The objective factor cost for each site may now be calculated by summing the costs in Tables 3-1 through 3-3 and applying Equation 3-2. Table 3-4 shows the resulting total objective factor costs along with the objective factor measures for each site.

Table 3-4. Total objective factor cost and measure for each site

Site	Total Objective Factor Cost (OFC)	Objective Factor Measure (OFM)
1	$ 28,237	.17433
2	$ 29,275	.16814
3	$ 29,266	.16819
4	$ 29,531	.16669
5	$ 29,732	.16556
6	$ 31,334	.15709

For example, the objective factor measure for site 1 in Table 3-4 is calculated as follows:

$$OFM_1 = [OFC_1 \cdot (\sum_i 1/OFC_i)]^{-1}$$
$$= [28{,}237(1/28{,}236 + 1/29{,}275 + 1/29{,}266 + 1/29{,}732 + 1/31{,}332)]^{-1}$$
$$= .17433$$

Evaluating subjective factor measures for each site. The subjective factor measure for any site "i" (SFM_i) is defined in Chapter II, Equation 2-8 as:

$$SFM_i = \sum_k (SFW_k \cdot SW_{ik}) \qquad (3-6)$$

where:

1. SFW_k is the weight of subjective factor "k" relative to all subjective factors, and

2. SW_{ik} is the weight of site "i" relative to all potential sites for subjective factor "k".

In order to determine the values of SFM_i for all "i", terms SFW_k and SW_{ik} are evaluated using the technique previously referred to as preference theory.

Consider first the subjective factor weights. The perference matrix[16] used to weight the subjective factors listed in Appendix A is shown in Table 3-5. Decision 1 (Table 3-5) implies that the decision maker considers factor "availability of transportation" more important than factor "industrial sites". To illustrate further, decisions 11 and 13 imply that the decision maker is indifferent towards factor "availability of transportation" and factors "competition" and "availability of labor".

---

[16]The preference values shown in Table 3-5 are theoretical and would normally represent policies and practices of the management of the locating plant.

Table 3-5. Preference matrix for subjective factors

Property	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
Availability of Transportation	1	1	1	1	1	1	1	1	1	1	0	1	0																																	
Industrial Sites	0													1	1	1	1	1	0	1	1	1	0	1	0																					
Climate		0												0												1	0	0	0	0	0	0	1	0	0	0										
Educational Facilities			0												0											0											0	0	0	0	0	0	0	0	0	0
Union Activity				0												0											1										1									
Recreation Facilities					0												0											1										1								
Housing						0												0											1										1							
Future Growth							0												1											1										1						
Community Services								0												0											1										1					
Employee Transportation Facilities									0												0											1										1				
Cost of Living										0												0											0										1			
Competition											0												1											1										1		
Complementary Industries												0												0											1										1	
Availability of Labor													0												1											1										1

Property	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
Availability of Transportation																																													
Industrial Sites																																													
Climate																																													
Educational Facilities																																													
Union Activity	1	1	0	0	1	1	0	0	0																																				
Recreation Facilities	0									1	0	0	1	1	0	0	0																												
Housing		0								0								0	0	0	1	0	0	0																					
Future Growth			1								1							1							1	1	1	0	1	0															
Community Services				1								1							1						0						1	1	0	0	0										
Employee Transportation Facilities					0								0							1						0					0					1	0	0	0						
Cost of Living						0								0							0						0					0				0				0	0	0			
Competition							1								1							1						1					1				1			1			1	0	
Complementary Industries								1								1							1						0					1				0			1		0		0
Availability of Labor									1								1							1						1					1				1			1		0	1

Subjective factor weights for each factor are then determined by summing the number of times each factor was preferred (considered more important) and dividing each sum by the total number of preferred decisions. A list of the subjective factor weights calculated from Table 3-5 is shown in Table 3-6. In Table 3-6 the weight of factor "availability of transportation" (.12644) is the quotient of 11 (number of times it was preferred) divided by 87 (total number of "preferred" decisions).

Table 3-6. Factor weights for subjective factors

Property	Sum of Preference Values*	Factor Weight
Availability of Transportation	11	.12644
Industrial Sites	9	.10345
Climate	2	.02299
Educational Facilities	0	.00000
Union Activity	6	.06897
Recreation Facilities	5	.05747
Housing	3	.03448
Future Growth	10	.11494
Community Services	7	.08046
Employee Transportation Facilities	4	.04598
Cost of Living	1	.01149
Competition	11	.12644
Complementary Industries	7	.08046
Availability of Labor	11	.12644
Total	87	1.00000

*Calculated from Table 3-5

Site weights are determined utilizing basically the same procedure used to evaluate subjective factor weights. The only difference in the two procedures is that site weights are evaluated on the basis of decision data at the sites while subjective factor weights are evaluated on the basis of company policies and practices. Appendix A, Tables A-20 through A-39, shows the information to be used in determining site weights for each subjective factor.

As an example, consider evaluating the site weights for subjective factor "availability of transportation". Table 3-7 shows the preference matrix with site weights for this factor. The matrix was arrived at by first subjectively examining the data in Appendix A, Tables A-20, A-21 and A-22. Then on the basis of this examination, the sites were compared two at a time. Decision 1 (Table 3-7) indicates that site 1 was preferred to site 2 for factor "availability of transportation". This decision was made because site 1 had more desirable transportation facilities than site 2.

Site weights for factor "availability of transportation" are then determined by dividing the number of preferred decisions by the total. For example, the site weight (.2000) for site 1 and factor "availability of transportation" is the quotient of 3 (number of times it was preferred) divided by 15 (total number of preferred decisions).

Appendix B displays the preference matrices used to calculate the site weights for each of the remaining subjective factors and Table 3-8 shows the resulting site weights calculated from these matrices.

Table 3-7. Preference matrix and site weights for factor "availability of transportation"

Property	Decision 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Sum of Preference Values	Site Weight
Site 1	1	0	0	1	1											3	.20000
Site 2	0					0	0	0	1							1	.06667
Site 3		1				1				1	1	1				5	.33333
Site 4			1				1			0			1	1		4	.26667
Site 5				0				1			0		0		1	2	.13333
Site 6					0				0			0		0	0	0	.00000
												Total				15	1.00000

Table 3-8. Site weights for each subjective factor

Subjective Factor	Site Number	Site Weight
Availability of Transportation	1	.20000
	2	.06667
	3	.33333
	4	.26667
	5	.13333
	6	.00000
Industrial Sites	1	.20000
	2	.06667
	3	.13333
	4	.33333
	5	.26667
	6	.00000
Climate	1	.25000
	2	.16667
	3	.08333
	4	.25000
	5	.25000
	6	.00000
Educational Facilities	1	.14286
	2	.35714
	3	.14286
	4	.28571
	5	.07143
	6	.00000
Union Activity	1	.33333
	2	.26667
	3	.06667
	4	.20000
	5	.13333
	6	.00000

Table 3-8. Continued

Subjective Factor	Site Number	Site Weight
Recreation Facilities	1	.07143
	2	.35714
	3	.21429
	4	.28571
	5	.07143
	6	.00000
Housing	1	.26667
	2	.20000
	3	.06667
	4	.33333
	5	.13333
	6	.00000
Future Growth	1	.21429
	2	.14286
	3	.07143
	4	.21429
	5	.35714
	6	.00000
Community Services	1	.28571
	2	.07143
	3	.14286
	4	.21429
	5	.28571
	6	.00000
Employee Transportation Facilities	1	.26667
	2	.13333
	3	.06667
	4	.20000
	5	.33333
	6	.00000

Table 3-8. Continued

Subjective Factor	Site Number	Site Weight
Cost of Living	1	.07692
	2	.23077
	3	.07692
	4	.38462
	5	.23077
	6	.00000
Competition	1	.20000
	2	.20000
	3	.20000
	4	.20000
	5	.20000
	6	.00000
Complementary Industries	1	.28571
	2	.21429
	3	.07143
	4	.07143
	5	.35714
	6	.00000
Availability of Labor	1	.20000
	2	.06667
	3	.13333
	4	.33333
	5	.26667
	6	.00000

Subjective factor measures for each site may now be calculated by applying Equation 3-6 to the data in Tables 3-6 and 3-8. Table 3-9 shows the resulting subjective factor measures for each site. For example, the subjective factor measure for site 1 in Table 3-9 is calculated as follows:

$$SFM_1 = \sum_k (SFW_k \cdot SW_{1k})$$
$$= (.12644)(.20000) + (.10345)(.20000) + \ldots$$
$$\ldots + (.12644)(.20000)$$
$$= .22234$$

Table 3-9. Subjective factor measures for each site

Site	Subjective Factor Measure
1	.22234
2	.14688
3	.14861
4	.24432
5	.23785
6	.00000

Evaluating location measures for each site. The location measure for any site "i" is defined in Equation 3-1 as:

$$LM_i = X \cdot OFM_i + (1-X) \cdot SFM_i \qquad (3\text{-}7)$$

where:

1. OFM_i is the measure of the objective factors for site "i"
2. SFM_i is the measure of the subjective factors for site "i", and
3. X is the objective factor decision weight.

Assuming an arbitrary value of .8 for the objective factor decision weight (X) and applying Equation 3-7 to the data in Tables 3-4 and 3-9, the location measures for the various sites can be calculated. Table 3-10 shows the resulting location measures for the six cities under consideration. Since site 1 has received the largest location measure (Table 3-10) it would be selected as the new location on the basis of X equal to exactly .8.

Table 3-10. Location Measures for each site (X = .8)

Site	Objective Factor Measure	Subjective Factor Measure	Location Measure
1	.17433	.22234	.18393
2	.16814	.14688	.16389
3	.16819	.14861	.16428
4	.16669	.24432	.18222
5	.16556	.23785	.18001
6	.15709	.00000	.12567

For example, the location measure for site 1 in Table 3-10 is calculated as follows:

$$LM_1 = X \cdot OFM_1 + (1-X) \cdot SFM_1$$
$$= (.8)(.17433) + (.2)(.22234)$$
$$= .18393$$

<u>Sensitivity to changes in decision weight</u>. As stated in Chapter II, the value of the objective factor decision weight may be subject to error. As a safety precaution the sensitivity of the location measures to changes in the objective factor decision weight should be investigated before the best site is selected. Figure 3-1 illustrates the changes in location measures for each site and various values of X.

A change in the best location is detected when the objective factor decision weight is equal to approximately .75 (Figure 3-1). The final decision, that of selecting the best site, is now made with the knowledge that if site 1 is selected and the estimated value of X (.8) is overestimated by 6 percent, the wrong site will be chosen.

<u>Sensitivity to input data</u>. As observed in the previous section, changes in the objective factor decision weight affects the selection of the best site. The best site can also be affected by changing various input data. Changes in labor, utilities, and production requirements are good examples of input data that can affect the choice of locations.

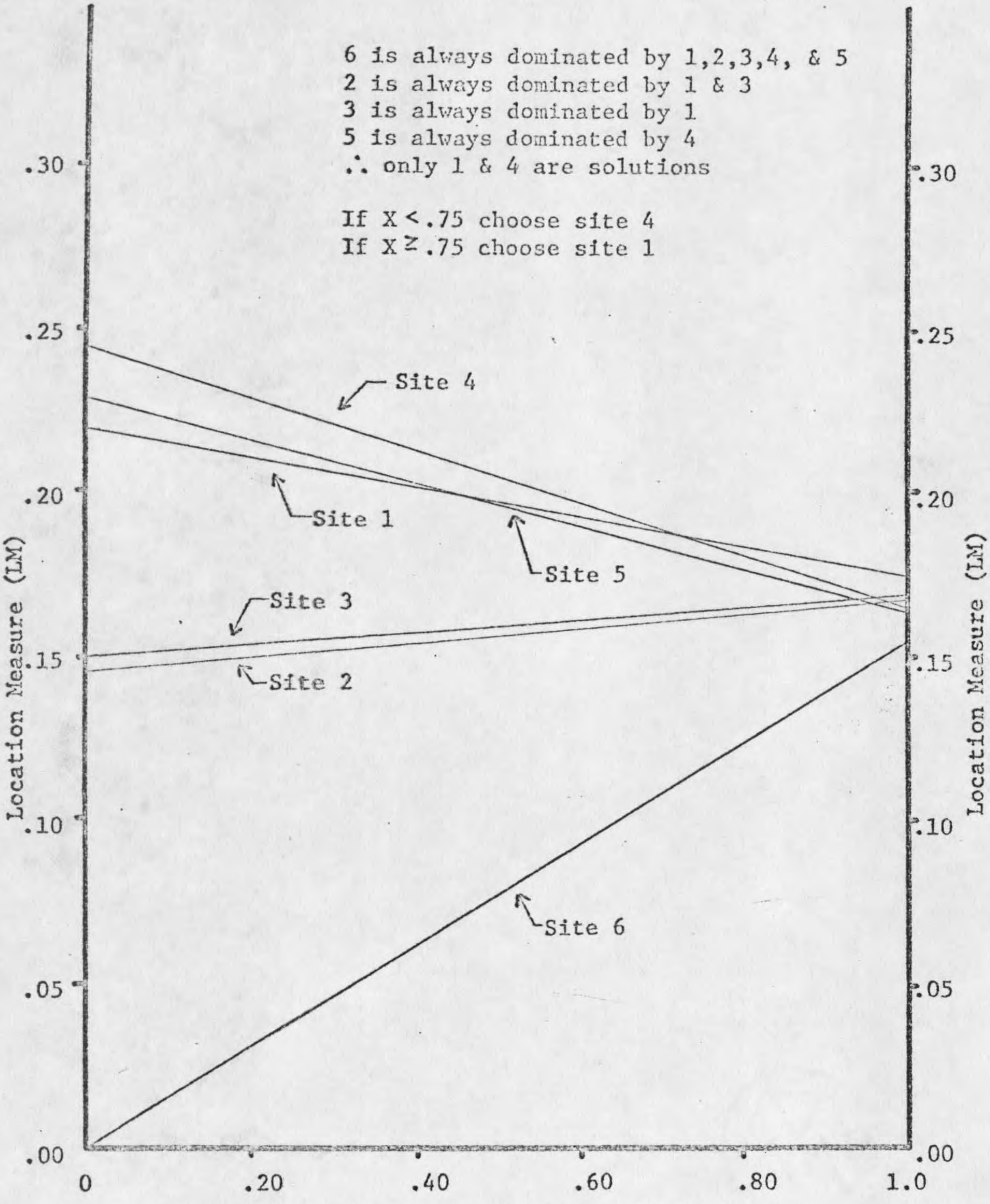

Figure 3-1. Sensitivity of location measures to changes in objective factor decision weight

As an example, consider that the estimated production rate for the previous example problem (150,000 lbs./mo.) may be subject to error but that all other input data is correct. The test for sensitivity of location measures to changes in production rates is conducted by first re-evaluating the total objective factor costs for each site according to the following assumptions:[17]

1. Raw material and finished product costs are nonlinear functions of the production rate.
2. Utilities, taxes, and building costs are independent of production rates.
3. Un-skilled, semi-skilled, and supervisory labor varies directly with production rates and administrative labor costs are independent of production rates.

For each production rate there will be a corresponding set of total objective factor costs. Each set of costs are converted to measures according to Equation 3-2 and combined with the constant subjective factor measures to produce a new set of location measures. These new sets of location measures can then be analyzed to assess the stability of the site selection with respect to production rate changes.

[17] These assumptions can vary from problem to problem.

For example, the objective factor costs for site 1 at a production rate of 50 percent (75,000 lbs./mo.) are calculated as follows:

1. Raw Material Cost (TRC_{ij})

   $TRC_{11} = (.003567)(256)^{.509}(100,000)^{.8319} = \$866$

   $TRC_{12} = (.003567)(224)^{.509}(100,000)^{.8319} = \$809$

   $TRC_{13} = (.003567)(127)^{.509}(100,000)^{.8319} = \$606$

   Therefore, the raw material cost is $606.

2. Finished Product Cost (MC_i)

   a. $MC_1 = a(256)^b(167)^c + a(0)^b(22,258)^c + a(142)^b(2,028)^c + \ldots$

   $\ldots + a(308)^b(1,199)^c + a(280)^b(1,295)^c$

   b. a = .003567, b = .509, and c = .8319

   c. $MC_1 = \$737$

3. Utility Cost (1) = $9,460 (same as 100 percent production rate)

4. Labor Cost (1) = [(6)(1.75)+(6)(2.50)][173] + (2)(750) + (1)(950)

   = $6,861.50

5. Building Cost (1) = $514 (same as 100 percent production rate)

6. Tax Cost (1) = $3,095 (same as 100 percent production rate)

Therefore, the total objective factor cost for site 1, at a production rate of 50 percent is $21,273. Appendix C displays the remaining objective factor costs for each site at production levels of 50 percent, 75 percent, 100 percent, 125 percent, and 150 percent of the original production level (150,000 lbs./mo.).

The total objective factor costs for each site and each production level (Appendix C) can now be converted to dimensionless indexes according to Equation 3-2. The resulting objective factor measures for each site and various production levels are shown in Table 3-11.

Table 3-11. Objective factor measures for various production levels

Site	Production Rate 50%	75%	100%	125%	150%
1	.17981	.17671	.17433	.17244	.17093
2	.16617	.16728	.16814	.16880	.16933
3	.16186	.16540	.16819	.17045	.17231
4	.16789	.16724	.16669	.16625	.16588
5	.16583	.16571	.16556	.16540	.16525
6	.15844	.15766	.15709	.15665	.15629

Combining each set of objective factor measures (one set for each production level) with the constant subjective factor measures (Table 3-9) and X equal to .8, produces five sets of location measures for each site. Figure 3-2 graphically displays the change in location measures for each site as production levels change and X = .8.

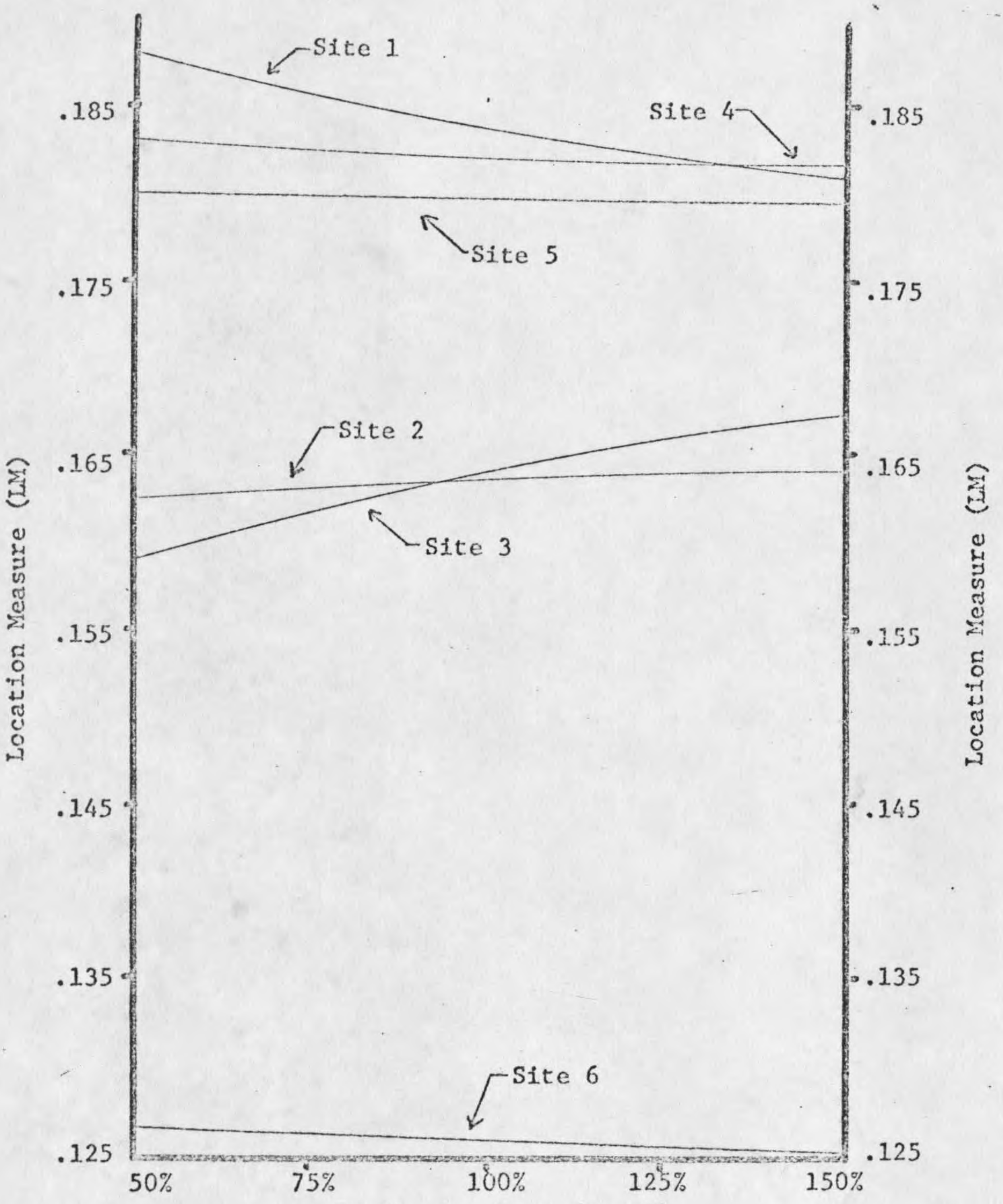

Figure 3-2. Sensitivity of location measures to production rate changes (X = .8)

Table 3-12 summarizes the change in the best location for various objective factor decision weights as the production level changes.

Table 3-12. Best location for various production rates (levels) and objective factor decision weights

Objective Factor Decision Weight	Production Rate 50%	75%	100%	125%	150%
.0	4	4	4	4	4
.1	4	4	4	4	4
.2	4	4	4	4	4
.3	4	4	4	4	4
.4	4	4	4	4	4
.5	4	4	4	4	4
.6	4	4	4	4	4
.7	1	4	4	4	4
.8	1	1	1	1	4
.9	1	1	1	1	1
1.0	1	1	1	1	3

It may be noted that with the objective factor decision equal to .8, the best location changes between 125 percent and 150 percent of the estimated production rate (50,000 lbs./mo.). Referring to Figure 3-2, the estimated production rate at which the change occurs is 135 percent.

Therefore, the final decision, that of selecting the best site, is now made with the knowledge that if site 1 is selected and either the value of the objective factor decision weight is overestimated by 6 percent or the production rate is underestimated by approximately 35 percent the wrong site will be chosen.

Chapter IV

CRITIQUE

The location model formulated in Chapter II is an approximation technique for selecting the best location for a plant. Although this technique solves several of the problems encountered by previous location models, it still has certain limitations.

The validity of the proposed model is affected by two possible sources of error in the approach (preference theory) used to quantify subjective factors. One source of error, characteristic of preference theory, is due to restrictions placed on the number of alternatives for each decision. In preference theory only three alternatives, out of an infinite number of alternatives, are defined for each decision. Restricting the number of possible alternatives to three reduces the reliability of the estimated weights for highly distinguishable properties.[18] For example, consider the case of determining property weights for three properties where the true property weights (TPW) are:

1. TPW(1) = 4/7
2. TPW(2) = 1/7
3. TPW(3) = 2/7

---

[18]This is a case where certain properties can be distinguished as being twice as important as other properties, three times as important, etc.

The estimated property weights (PW) derived with the application of preference theory, assuming that the magnitudes of the true property weights determine preferences, would be:

1. PW(1) = 2/3
2. PW(2) = 0
3. PW(3) = 1/3

Comparing the true property weights to the estimated weights reveals that the estimated weights are not representative. If this situation occurs frequently in a plant location problem the wrong conclusion could be made.

A possible solution to this problem could be an extension of preference theory to include more than three alternatives, such as a five alternative process: highly preferred, preferred, indifferent, not preferred, and highly not preferred. Table 4-1 shows a set of suggested values and conditions for selecting the proper alternative for this five alternative process.

Table 4-1. Values and conditions for a five alternative preference approach

Alternative	Preference Value	Magnitude of Property Importance (X)*
Highly Preferred	2.0	$X > 2$
Preferred	1.5	$1 < X \leq 2$
Indifferent	1.0	$X = 1$

Table 4-1. Continued

Alternative	Preference Value	Magnitude of Property Importance (X)*
Not Preferred	1.0	$.5 \leq X < 1$
Highly Not Preferred	0.0	$X < .5$

*Magnitude of property importance (X) is the numerical value defining the relative importance of one property to another. For example, if property A is four times as important as property B, then X is equal to 4 and property A is considered to be highly preferred to property B.

Property weights developed by applying the five alternative preference approach to the previous example, assuming that the magnitude of the true property weights can be used to define the magnitude of property importance, are:

1. PW(1) = 3.5/7
2. PW(2) = 1.0/7
3. PW(3) = 2.5/7

Comparing the true property weights to the two sets of estimated property weights indicates that the extended preference approach is superior to the standard preference approach for highly distinguishable properties. Although the preceding example does not conclusively prove the superiority of an extended preference approach, it does imply this possibility.

A second possible source of error in the proposed model, due to the application of preference theory, is from a decision maker developing an intransitive preference matrix.[19] To insure that this error is not made, each preference matrix should be checked for intransitivity. A preference matrix can be checked for intransitivity by developing a new matrix[20] based on the magnitude of the original property weights. For example, the new matrix should be developed so that the property with the largest property weight is preferred to all other properties, the property with the next largest property is preferred to all properties except the property with the largest weight, etc. If the new matrix agrees with the original matrix, transitivity of preferences has been preserved. However, if the two matrices do not agree, the matrix is intransitive and the decision maker must reevaluate his decisions and try to alleviate this problem.

Another possible source of error characteristic of the proposed model is the objective factor decision weight. Even though this problem is overcome to some extent by applying a sensitivity analysis, development of a systematic approach to quantify the objective factor decision weight would increase the validity of the model.

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[19]An intransitive preference matrix is one that includes contradictory decisions.

[20]For ease of comparison, properties should be listed in the same order in both matrices.

As previously stated at the beginning of this chapter there are several advantages characteristic of the proposed model. One advantage is that it not only considers cost factors (objective factors), but it also reduces the number of sites under consideration with the use of critical factors and systematically evaluates sites on the basis of subjective factors as well.

A second advantage is that the model is not limited to any specific type or number of location factors. To illustrate this flexibility, consider the problem of developing preference matrices for subjective factor site weights. As the amount of information necessary to evaluate a subjective factor increases, comparing sites becomes a difficult if not insurmountable task. This problem can be alleviated by extending the definition of the subjective factor index to include subjective subfactors. The new definition for the subjective factor index would be:

$$SFI_i = \sum_k SFW_k \left(\sum_m SSW_{km} \cdot SW_{ikm}\right) \qquad (4\text{-}1)$$

where:

1. SFW_k is the weight of subjective factor "k"
2. SSW_{km} is the weight of subjective subfactor "m" for subjective factor "k", and
3. SW_{ikm} is the weight of site "i" relative to all potential sites for subjective subfactor "km".

Values for subjective subfactor weights are determined using a preference approach and site weights must now be evaluated for each subfactor. If the information defining each subfactor is still too large or complex to evaluate site weights effectively, the subjective factor index can be extended to include additional subdivisions.

In addition, previous advantages permit the model to be applied to practical problems. As illustrated in Chapter III, variables inherent in the model can be quantified and a definite solution reached.

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APPENDICES

Appendix A

Location Data for Plant Location Model

The following list of factors and the data defining these factors is presented for the purpose of illustrating the application of the location model in Chapter III.

Critical Factors

Availability of Utilities

Table A-1. Minimum utilities available

Utility	Site 1	2	3	4	5	6
Electricity	*	*	*	*	*	*
Gas	*	*	*	*	*	*
Water & Sewage	*	*	*	*	*	*

*No minimum

Community Attitude

Table A-2. Attitude towards industry

Site	Is Industry Accepted?	Site	Is Industry Accepted?	Site	Is Industry Accepted?
1	Yes	3	Yes	5	Yes
2	Yes	4	Yes	6	Yes

Objective Factors

Cost of Transporting Raw Materials

Table A-3. Raw material requirements

Raw material requirements (lbs./mo.).	200,000
Number of sources of raw material	3
Cost of raw material* ($/lb.)	1

*Same at all three sources

Table A-4. Distance (miles) from potential sites to raw material sources

	Source		
Site	1	2	3
1	256	224	127
2	114	98	162
3	27	64	241
4	105	116	272
5	175	94	106
6	485	423	245

Table A-5. Empirical data for regression analysis to determine the constants a, b, and c in Equation 3-4*

Sample Number	Total Cost (TRC)	Distance (X)	Weight (Y)
1	32.60	266	2,000
2	51.50	142	5,000
3	34.21	154	2,700
4	114.75	325	7,500
5	94.00	515	4,000
6	36.60	165	3,000
7	23.52	64	2,800
8	51.24	209	4,200
9	48.96	220	3,600
10	61.80	446	3,000

*Total cost is the dependent variable and distance and weight are the independent variables. For a detailed discussion on regression analysis, see Miller and Freund [11].

Cost of Transporting Finished Product

Table A-6. Finished product requirements

Production rate (lbs./mo.)	150,000
Number of markets	18
Selling price at markets	*

*Same price at all eighteen markets

Table A-7. Distance (miles) from sites to markets

Market Number	Site 1	2	3	4	5	6
1	256	114	27	105	175	485
2	0	142	229	340	220	229
3	142	0	87	208	192	371
4	229	87	0	121	158	458
5	330	288	254	242	110	435
6	269	127	40	81	149	478
7	279	366	429	437	271	150
8	119	371	458	517	351	0
9	220	192	158	166	0	351
10	250	304	270	278	112	309
11	224	98	64	116	94	423
12	447	324	237	116	227	571
13	127	162	241	272	106	245
14	117	25	112	233	172	346
15	153	295	382	463	318	77
16	340	208	121	0	166	517
17	308	266	232	228	88	411
18	280	422	509	543	377	53

Table A-8. Amount of finished product (lbs.) shipped to each market

Market Number	Weight of Finished Product	Market Number	Weight of Finished Product
1	334	10	7,432
2	44,516	11	5,454
3	4,056	12	5,484
4	12,818	13	3,535
5	1,804	14	1,647
6	420	15	5,765
7	4,092	16	14,318
8	2,705	17	2,399
9	30,631	18	2,590

Table A-9. Empirical data for regression analysis to determine the constants a, b, and c in Equation 3-5*

Sample Number	Total Cost (MC)	Distance (X)	Weight (Y)
1	32.60	266	2,000
2	51.50	142	5,000
3	34.21	154	2,700
4	114.75	325	7,500
5	94.00	515	4,000
6	36.60	165	3,000
7	23.52	64	2,800
8	51.24	209	4,200
9	48.96	220	3,600
10	61.80	446	3,000

*Total cost is the dependent variable and distance and weight are the independent variables. For a detailed discussion on regression analysis, see Miller and Freund [11].

Cost of Utilities

Table A-10. Utility requirements

Average monthly gas requirements (MCF)	20,000
Average monthly electricity requirements (kwh.) . . .	5,000
Average monthly water & sewage requirements (cu.ft.).	20,000

Table A-11. Cost of electricity*

$1.25	for the first 20 kwh. or less	
4.0¢	per kwh. for the next	80 kwh.
3.4¢	per kwh. for the next	1,700 kwh.
2.0¢	per kwh. for the next	3,200 kwh.
1.1¢	per kwh. for the next	15,000 kwh.
.94¢	per kwh. for the next	200 kwh.
.60¢	per kwh. for all additional kwh.	

Plus

First 10 kilowatts	no charge
Next 20 kilowatts	$ 1.20/KW.
All additional kilowatts	$ 1.00/KW.

*The electrical rates are the same for all cities and will not be considered in the cost analysis in Chapter III. This table serves only as an illustration.

Table A-12. Cost of gas ($/MCF.)

Amount (B_j)	Site 1	Site 2,3,4,&5
First 1 MCF.	.33	2.50
Next 99 MCF.	.33	.74
Next 200 MCF.	.33	.54
Next 700 MCF.	.33	.42
Next 4,000 MCF.	.33	.38
All additional	.33	.32

Table A-13. Cost of water and sewage ($/cu.ft.)

Amount (D_j) (cu.ft.)		Site 1	2	3	4	5	6
First	500	.33	.55	.39	.30	.40	.55
Next	500	.33	.38	.39	.30	.40	.38
Next	500	.19	.38	.37	.30	.35	.38
Next	500	.19	.30	.37	.30	.35	.30
Next	500	.13	.30	.35	.30	.35	.30
Next	500	.13	.25	.35	.30	.35	.25
Next	2,000	.13	.25	.33	.30	.35	.25
Next	2,500	.13	.25	.31	.15	.20	.25
Next	2,500	.13	.25	.29	.15	.20	.25
Next	10,000	.13	.20	.27	.15	.13	.20
Next	30,000	.13	.20	.27	.12	.13	.20
Next	20,000	.10	.15	.27	.12	.13	.15
Next	10,000	.10	.15	.24	.12	.13	.15
Next	20,000	.10	.15	.24	.08	.13	.15
Next	80,000	.07	.15	.24	.08	.11	.15
Next	220,000	.07	.15	.24	.07	.11	.15
Next	100,000	.07	.10	.24	.07	.11	.10
Next	500,000	.07	.10	.24	.04	.11	.10
All Additional		.06	.10	.21	.02	.11	.10

Cost of Labor

Table A-14. Labor requirements

Number of unskilled workers required	12
Number of semi-skilled workers required	12
Number of supervisors required	4
Number of administrators required	1
Number of working hours per month	173

Table A-15. Cost of labor

Type of Labor	Site 1	2	3	4	5	6
Unskilled*	1.75	1.50	1.25	1.65	1.75	1.80
Semi-skilled*	2.50	2.10	2.00	2.35	2.30	2.20
Supervisory**	750	725	700	730	750	760
Administrative**	950	875	875	935	925	900

*Cost per hour

**Cost per month

Cost of Building

Table A-16. Building requirements

Configuration of building	Rectangular
Type of building	Structural
Size of basement (sq.ft.)	2,500
Size of first floor (sq.ft.).	2,500
Estimated life of building (yrs.)	20
Capital recovery factor for 20 year life and interest at 10%	.1175

Table A-17. Cost of building ($/sq.ft.)

	Site					
Floor Level	1	2	3	4	5	6
Basement	6.00	7.00	7.00	6.00	8.00	8.00
First Floor	15.00	16.00	15.00	14.00	17.00	17.00

Cost of Taxes

Table A-18. Tax information

Value of facilities ($)	500,000
Percent of value taxable	40
Annual net sales ($).	1,000,000

Table A-19. Property and sales tax for each site (mills/yr.)

	Site					
Type of Tax	1	2	3	4	5	6
Property	185.69	208.23	214.82	225.28	222.09	203.60
Sales	*	*	*	*	*	*

*The sales tax is the same at each site.

Subjective Factors

Availability of Transportation

Table A-20. Airline service

Site	Airlines* 1	2	3	Total Daily Flights	Type of Service** 1	2	3
1	x	x	x	32	x	x	x
2	x	x		10	x	x	x
3	x		x	10	x	x	x
4	x	x		18		x	x
5	x	x	x	30	x	x	x
6		x		4		x	x

* 1 - Northwest Orient
2 - Frontier
3 - Western

** 1 - Jet
2 - Prop Jet
3 - Prop

Table A-21. Common carriers

Site	Railroads* 1	2	3	4	5	Motor Carriers Local	Inter State	Intra State	Total
1	x		x	x		21	12	17	50
2		x		x		1	2	1	4
3	x	x		x	x	3	6	2	11
4		x		x		1	6	9	16
5	x	x				0	12	3	15
6				x		1	0	1	2

* 1 - Great Northern, 2 - Chicago, Milwaukee, St. Paul, & Pacific, 3 - Chicago, Burlington, & Quincy, 4 - Northern Pacific, 5 - Union Pacific.

Table A-22. Highways

Site	Major Highways	Destination	Road Condition
1	I.S. 90	Seattle - Denver	Excellent
	I.S. 94	Minn./St. Paul	Excellent
	U.S. 87	Great Falls	Good
2	I.S. 90	Seattle - Denver	Excellent
	U.S. 191	Salt Lake - Great Falls	Good
3	I.S. 90	Seattle - Denver	Excellent
	I.S. 15	Salt Lake - Great Falls	Excellent
4	I.S. 90	Seattle - Denver	Excellent
	U.S. 93	Kalispell - Salt Lake	Good
5	I.S. 15	Great Falls - Salt Lake	Excellent
	U.S. 87	Billings - Missoula	Fair
6	I.S. 94	Billings - Minn./St. Paul	Excellent

Table A-23. Description of industrial sites

Site	Total Acreage	Description	Transportation Access	Price	Zoning	Utilities
1	592	Unimproved & level	Highway - 1 mile Rail - spurs Airport - 5-9 mi.	*	None	Unavail.
2	310	Unimproved & level	Highway - 1 mile Rail - spurs Airport - 11 mi.	Lease only	Indus.	Unavail.
3	415	Unimproved & level	Highway - 2 mile Rail - spurs Airport - 1 mile	*	Indus.	Unavail.
4	100	Improved & level	Highway - adj. Rail - spurs Airport - adj.	*	Indus.	Avail.
5	615	Unimproved & level	Highway - 1 mile Rail - spurs Airport - 7 mile	*	Indus.	Avail.
6	Presently do not have land set aside for industrial sites.					

*Price unknown.

Climate.

Table A-24. Weather conditions

Site	Average Number Days Between Freeze	Average Number Days Temp. Below 32°	Average Number Days with Precipitation	Mean Temp Feb.	Mean Temp July
1	132	45	91	26	73
2	115	54	51	24	66
3	110	62	107	19	62
4	128	46	121	26	68
5	139	48	97	25	70
6	134	58	32	19	75

Educational Facilities.

Table A-25. Number of schools

Site	Grade Schools	Junior Highs	High Schools	Trade Schools	Colleges	Univ.
1	34	5	2	11	2	0
2	6	2	2	1	0	1
3	17	2	2	2	1	0
4	17	3	3	7	0	1
5	18	3	3	8	1	0
6	4	1	1	0	1	0

Table A-26. Library facilities and degrees offered at colleges and universities

Site	Degrees Offered					Libraries	
	B.A.	B.S.	M.A.	M.S.	PhD.	Number	Circulation
1	yes	yes	yes	yes	no	3	184,600
2	yes	yes	yes	yes	yes	2	408,500
3	yes	yes	yes	yes	no	3	134,000
4	yes	yes	yes	yes	yes	3	507,000
5	yes	yes	no	no	no	3	162,200
6	yes	no	no	no	no	1	50,000

Union Activity.

Table A-27. Union Activity

Site	Total Number of Unions	Number of Major Strikes (last 5 yr.)	Principle Union to Participate in Strike
1	17	0	-
2	23	0	-
3	26	1	Steel Workers (9 mo.)
4	26	0	-
5	26	1	Steel Workers (4 mo.)
6	21	1	Steel Workers (1 yr.)

Recreation Facilities.

Table A-28. Recreation facilities

Site	Public Bowling Alleys	Golf Courses Public	Golf Courses Private	Snow Skiing Facilities	Theaters	City Parks
1	5	1	2	1	6	18
2	1	0	2	1	3	7
3	4	1	1	3	2	5
4	3	2	1	3	6	19
5	4	1	1	1	6	48
6	1	0	1	0	1	4

Housing.

Table A-29. Housing

Site	Average Number Persons/Room	% Crowded Dwellings	Median Price	% Sound Dwellings
1	3	12.1	14,700	76.0
2	3	10.9	12,100	72.4
3	3	13.2	8,100	69.9
4	3	14.1	12,900	76.1
5	3	15.6	13,500	71.2
6	4	18.4	13,900	72.9

Future Growth.

Table A-30. Population characteristics

	Total County Population			County Population (Age 20-40)		
Site	1960	1970	% Change	1960	1970	% Change
1	79,016	107,034	35	20,770	28,201	25
2	26,045	32,653	23	7,475	10,072	35
3	46,454	42,272	-9	9,599	8,728	-9
4	44,663	58,324	32	11,916	15,725	32
5	73,418	102,993	41	20,922	31,023	48
6	12,314	15,433	25	3,126	4,131	32

Table A-31. Value of building permits and number of new dwellings

	Value of Building Permits ($1,000)				# of New Dwellings		
Site	1965	1966	1967	1968	1967	1968	1969*
1	8,468	8,171	7,480	9,755	316	311	201
2	7,964	4,280	4,436	3,550	89	151	74
3	433	2,447	2,630	577	165	140	64
4	6,831	7,961	3,356	5,947	241	206	180
5	8,621	7,464	7,415	5,260	308	300	150
6	1,252	1,452	978	423	60	77	25

*Through June 1, 1969.

Community Services.

Table A-32. Police department, fire department and medical statistics

Site	Police Department: Number of Officers	Police Department: Number of Patrol Cars	Fire Class.	Hospitals: Number	Hospitals: Beds	Number of Doctors
1	75	14	4	2	450	171
2	17	4	5	1	102	42
3	36	5	6	2	347	65
4	35	5	5	3	364	117
5	70	16	5	2	436	133
6	15	3	6	1	100	20

Table A-33. Communications facilities

Site	Total Number Newspapers	Number of Radio Stations: AM	Number of Radio Stations: FM	Number of Radio Stations: Stereo	T.V. Stations Received by: Antenna	T.V. Stations Received by: Cable
1	2	5	1	0	2	5
2	2	2	2	0	1	5
3	2	2	0	0	1	5
4	2	4	1	1	2	5
5	2	4	1	0	2	8
6	1	2	0	0	2	6

Employee Transportation Facilities.

Table A-34. Mileage of city streets by material

Site	Primary Surface	Secondary Surface	Gravel	Brick	Earth	Concrete	Total
1	111	99	28	1	4	4	247
2	37	27	1	0	1	0	66
3	73	3	0	1	13	2	92
4	125	2	7	0	17	2	153
5	228	9	4	0	2	3	246
6	2	38	5	0	5	0	50

Table A-35. Mileage of city streets by type

Site	Number of Lanes			Miles of One Way
	2	4	<4	
1	235	12	0	5
2	62	4	0	0
3	84	8	0	2
4	140	13	0	4
5	238	8	0	14
6	50	0	0	0

Cost of Living.

Table A-36. Income information

Site	Median Family Income	Median Price of Houses	Farm Living Index	Severity of Poverty Index
1	6,372	14,700	132	10.0
2	5,601	12,100	129	14.9
3	5,431	8,100	132	16.2
4	5,978	12,900	119	10.0
5	6,188	13,500	129	11.5
6	5,772	13,900	110	14.5

Competition. The product to be manufactured is new and there is no competition. Therefore, the site weights for this factor will be the same.

Complementary Industries.

Table A-37. Number of industries by type

Site	Machine Shops	Welding Shops	Sheet Metal Shops	Contractors		
				Building	Plumbing	Elect.
1	8	14	8	22	24	9
2	1	4	4	7	6	5
3	5	7	2	9	5	7
4	9	7	6	12	14	9
5	5	13	10	14	11	8
6	2	2	0	2	3	3

Availability of Labor.

Table A-38. General labor statistics

Site	Total Work Force	Non Ag. Work Force	Number Unemployed	Primary Employment
1	34,800	32,500	256	Health Services
2	11,000	9,600	100	Health Services
3	13,150	11,111	743	Metal Mining
4	18,678	18,000	550	Lumber
5	30,800	29,600	1,100	Metal Processing
6	4,153	2,522	177	Restaurants

Table A-39. Percent of total county employment by classification

Classification	Site 1	2	3	4	5	6
Ag. Services, Forestry and Fisheries	1	1	1	1	1	1
Mining	3	1	16	1	1	7
Contract Construction	8	6	5	5	11	6
Manufacturing	14	18	7	32	19	3
Transportation, Utilities & Sanitary Services	10	6	8	7	7	21
Wholesale Trade	14	6	7	8	9	8
Retail Trade	25	34	19	26	25	29
Finance, Insurance and Real Estate	7	6	4	5	8	5
Services	20	22	13	18	20	18

Appendix B

Preference Matrices for Subjective Factors

Table B-1. Availability of transportation

Site	Decision 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	0	0	1	1										
2	0					0	0	0	1						
3		1				1				1	1	1			
4			1				1			0			1	1	
5				0				1			0		0		1
6					0				0			0		0	0

Table B-2. Industrial sites

Site	Decision 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	0	0	1										
2	0					0	0	0	1						
3		0				1				0	0	1			
4			1				1			1			1	1	
5				1				1			1		0		1
6					0				0			0		0	0

Table B-3. Climate

Site	Decision 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	0	0	1										
2	0					1	0	0	1						
3		0				0				0	0	1			
4			0				1			1			0	1	
5				0				1			1		0		1
6					0				0			0		0	0

Table B-4. Educational facilities

Site	Decision 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	1	1										
2	1					1	1	1	1						
3		0				0				0	1	1			
4			1				0			1			1	1	
5				0				0			0		0		1
6					0				0			0		0	0

Table B-5. Union activity

Site	Decision 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1	1	1										
2	0					1	1	1	1						
3		0				0				0	0	1			
4			0				0			1			1	1	
5				0				0			1		0		1
6					0				0			0		0	0

Table B-6. Recreation facilities

Site	Decision 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	1										
2	1					1	1	1	1						
3		1				0				0	1	1			
4			1				0			1			1	1	
5				0				0			0		0		1
6					0				0			0		0	0

Table B-7. Housing

Site	Decision 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	0	1	1										
2	0					1	0	1	1						
3		0				0				0	0	1			
4			1				1			1			1	1	
5				0				0			1		0		1
6					0				0			0		0	0

Table B-8. Future growth

Site	Decision 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	0	0	1										
2	0					1	0	0	1						
3		0				0				0	0	1			
4			0				1			1			0	1	
5				1				1			1		1		1
6					0				0			0		0	0

Table B-9. Community services

Site	Decision 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1	0	1										
2	0					0	0	0	1						
3		0				1				0	0	1			
4			0				1			1			0	1	
5				0				1			1		1		1
6					0				0			0		0	0

Table B-10. Employee transportation facilities

Site	Decision 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1	0	1										
2	0					1	0	0	1						
3		0				0				0	0	1			
4			0				1			1			0	1	
5				1				1			1		1		1
6					0				0			0		0	0

Table B-11. Cost of living

Site	Decision 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	1										
2	1					1	0	0	1						
3		0				0				0	0	1			
4			1				1			1			1	1	
5				1				0			1		0		1
6					0				0			0		0	0

Table B-12. Competition

Site	Decision 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	1										
2	0					0	0	0	1						
3		0				0				0	0	1			
4			0				0			0			0	1	
5				0				0			0		0		1
6					0				0			0		0	0

Table B-13. Complementary industries

Site	Decision 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1	0	1										
2	0					1	1	0	1						
3		0				0				0	0	1			
4			0				0			0			0	1	
5				1				1			1		1		1
6					0				0			0		0	0

Table B-14. Availability of labor

Site	Decision 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	0	0	1										
2	0					0	0	0	1						
3		0				1				0	0	1			
4			1				1			1			1	1	
5				1				1			1		0		1
6					0				0			0		0	0

Appendix C

Objective Factor Costs for Various Production Rates

Table C-1. Production rate = 50%

Objective Factor	Site 1	2	3	4	5	6
Water	2,860	4,765	5,970	3,750	4,100	4,830
Labor	6,681	6,062	5,648	6,547	6,629	6,572
Taxes	3,095	3,470	3,580	3,755	3,701	3,393
Building	514	563	539	490	612	612
Finished Product	737	830	821	895	706	1,091
Raw Material	606	531	276	550	520	847
Gas	6,600	6,798	6,798	6,798	6,798	6,798
Total	21,273	23,019	23,632	22,785	23,066	24,143

Table C-2. Production rate = 75%

Objective Factor	Site 1	2	3	4	5	6
Water	2,860	4,765	5,970	3,750	4,100	4,830
Labor	9,817	8,655	8,035	9,353	9,481	9,408
Taxes	3,095	3,470	3,580	3,755	3,701	3,393
Building	514	563	539	490	612	612
Finished Product	1,033	1,169	1,153	1,255	991	1,534
Raw Material	849	744	386	771	728	1,186
Gas	6,600	6,798	6,798	6,798	6,798	6,798
Total	24,768	26,164	26,461	26,172	26,411	27,761

Table C-3. Production rate = 100%

Objective Factor	Site 1	2	3	4	5	6
Water	2,860	4,765	5,970	3,750	4,100	4,830
Labor	12,733	11,249	10,422	12,159	12,333	12,244
Taxes	3,095	3,470	3,580	3,755	3,701	3,393
Building	514	563	539	490	612	612
Finished Product	1,316	1,485	1,467	1,600	1,263	1,950
Raw Material	1,079	945	490	979	925	1,507
Gas	6,600	6,798	6,798	6,798	6,798	6,798
Total	28,237	29,275	29,266	29,531	29,732	31,334

Table C-4. Production rate = 125%

Objective Factor	Site 1	2	3	4	5	6
Water	2,860	4,765	5,970	3,750	4,100	4,830
Labor	15,729	13,842	12,809	14,965	15,185	15,080
Taxes	3,095	3,470	3,580	3,755	3,701	3,393
Building	514	563	539	490	612	612
Finished Product	1,587	1,791	1,767	1,927	1,523	2,349
Raw Material	1,299	1,138	590	1,179	1,114	1,814
Gas	6,600	6,798	6,798	6,798	6,798	6,798
Total	31,684	32,367	32,053	32,864	33,033	34,876

Table C-5. Production rate = 150%

Objective	Site 1	2	3	4	5	6
Water	2,860	4,765	5,970	3,750	4,100	4,830
Labor	18,684	16,435	15,195	17,771	18,037	17,916
Taxes	3,095	3,470	3,580	3,755	3,701	3,393
Building	514	563	539	490	612	612
Finished Product	1,844	2,085	2,058	2,243	1,772	2,737
Raw Material	1,511	1,324	687	1,372	1,297	2,112
Gas	6,600	6,798	6,798	6,798	6,798	6,798
Total	35,108	35,440	34,827	36,178	36,317	38,398

Appendix D

Computer Program for Plant Location Model

Problem Description

The location measure for each potential site is calculated according to Equation D-1:

$$LM = X \cdot (OFC_i \cdot \sum_i 1/OFC_i)^{-1} + (1-X) \cdot \sum_k SFW_k \cdot SW_{ik} \qquad \text{(D-1)}$$

where:

1. OFC_i is the total objective factor cost for site "i"
2. SFW_k is the weight of subjective factor "k" relative to all subjective factors
3. SW_{ik} is the weight of site "i" relative to all potential sites for subjective factor "k", and
4. X is the objective factor decision weight.

Program

The plant location program presented in this appendix consists of a main routine and several subroutines. Table D-1 shows the relationships among the programmed routines and the variables required to evaluate the location measure in Equation D-1. In addition to the routines named in Table D-1, routines named REGRES, CORRE, DATA, ORDER, MINV, and MULTR from the IBM Scientific Subroutine Package [12] are included. The purpose of these routines is to calculate the regression constants for determining the transportation costs of raw materials and finished products.

Table D-1. Relationships among program's routines and variables in Equation D-1.

Routine Name	Variable Calculated
MAIN	LM_i
SUBFAC	SFM_i
WEIGHT	SFW_k
SITEWT	SW_{ik}
COST	OFM_i and OFC_i
LABOR	Cost of Labor
MARKET	Cost of Marketing
RAWM	Cost of Raw Material
TAXES	Cost of Taxes
BUILD	Cost of Building
UTIL	Cost of Gas
WATER	Cost of Water & Sewage

Capacity

The capacity of the plant location program is limited to a minimum of:

1. Fifty potential sites
2. Fourteen subjective factors
3. Six objective factors
4. Ten different types of hourly paid workers

5. Ten different types of monthly paid employees

6. One hundred possible markets

7. Ten different types of finished products

8. Ten different types of raw materials, and

9. Five different sources for each raw material.

Except for the number of objective factors, the capacity of the program presented at the end of this appendix can be increased by changing the appropriate dimension statements. For every additional objective factor included in an analysis a separate subroutine must be written.

One other restriction on the capacity of the program is that the program was developed on the basis of the production rate assumptions in Chapter III: (1) utilities, taxes, and building costs are independent of production rates, (2) raw material and finished product costs vary directly with production rates, and (3) unskilled, semi-skilled, and supervisory labor costs vary directly with production rates. If any of these assumptions are deemed impractical, appropriate changes must be made.

Data Cards

Table D-2 is a presentation and general description of the input data cards required for the computer program at the end of this appendix. The data cards are presented in the order in which they must appear in the program. In cases where the number of variables to be read is also a variable, the code CARD#-a is used. For instance, 2-a implies that the number of type two data cards varies with each problem.

Table D-2. Description of input data for computer program

Card			Variable	
Number	Format	Columns	Name	Description
1	I3	1-3	NXX	Number of sites
2-a	13I2	1-2	INDEX(1,1)	Preference value of subjective factor 1 compared to subjective factor 2
		3-4	INDEX(1,2)	Preference value of subjective factor 1 compared to subjective factor 3
		⋮	⋮	⋮
			INDEX(14,13)	Preference value of subjective factor 14 compared to subjective factor 13
3-a	30I2	1-2	FAC(1,1)	Preference value for site 1 compared to site 2 for subjective factor 1
		3-4	FAC(1,2)	Preference value for site 1 compared to site 3 for subjective factor 1
		⋮	⋮	⋮
			FAC(NXX,NXX-1)	Preference value for site NXX compared to site NXX-1 for subjective factor 1
	30I2	1-2	FAC(1,1)	Preference value for site 1 compared to site 2 for subjective factor 2
	⋮	⋮	⋮	⋮
			FAC(NXX,NXX-1)	Preference value for site NXX compared to site NXX-1 for subjective factor 14
4	2I3	1-3	NHR	Number of different types of hourly paid employees
		4-6	MO	Number of different types of monthly paid employees

Table D-2. Continued

Card Number	Card Format	Columns	Variable Name	Variable Description
5-a	12F5.2	1-5	CHR(1,1)	Cost per hour of type 1 employee at site 1
		6-10	CHR(1,2)	Cost per hour of type 2 employee at site 1
		⋮	⋮	⋮
			CHR(NXX,NHR)	Cost per hour of type NHR employee at site NXX
6-a	15F4.0	1-4	CMO(1,1)	Cost per month of type 1 monthly paid employee at site 1
		5-8	CMO(1,2)	Cost per month of type 2 monthly paid employee at site 1
		⋮	⋮	⋮
			CMO(NXX,MO)	Cost per month of type MO monthly paid employee at site NXX
7-a	20I3	1-3	NUM1(1)	Number of type 1 hourly paid employees needed
		4-6	NUM1(2)	Number of type 2 hourly paid employees needed
		⋮	⋮	⋮
			NUM1(NHR)	Number of type NHR hourly paid employees needed
8-a	20I3	1-3	NUM2(1)	Number of type 1 monthly paid employees needed
		4-6	NUM2(2)	Number of type 2 monthly paid employees needed
		⋮	⋮	⋮
			NUM2(MO)	Number of type MO monthly paid employees needed
9	2I4	1-4	IN	Number of markets
		5-8	IM	Number of different products to be shipped

Table D-2. Continued

Card Number	Card Format	Columns	Variable Name	Variable Description
10-a	18F4.0	1-4	DIST(1,1)	Distance from market 1 to site 1
		5-8	DIST(1,2)	Distance from market 2 to site 1
		⋮	⋮	⋮
		⋮	DIST(NXX,IN)	Distance from market IN to site NXX
11-a	12F6.0	1-6	SALES(1,1)	Sales of product 1 at market 1
		7-12	SALES(1,2)	Sales of product 2 at market 1
		⋮	⋮	⋮
		⋮	SALES(IN,IM)	Sales of product IM at market IN
12*	A4,A2	1-6	PR,PR1	Problem name
	I5	7-11	N	Number of observations
	2I2	12-13	M	Number of variables
		14-15	NS	Number of selection cards
13-a*	3F6.0	1-6	D(1)	Transportation cost for observation 1
		7-12	D(2)	Distance shipped for observation 1
		13-18	D(3)	Weight of product for observation 1
	⋮	⋮	⋮	⋮
	3F6.0	1-6	D(1)	Transportation cost for observation N
		7-12	D(2)	Distance shipped for observation N
		13-18	D(3)	Weight of product for observation N
14-a*	5I2	1-2	NRESI	Option code for table of residuals
		3-4	NDEP	Dependent variable for regression test
		5-6	K	Number of independent variables
		7-8	ISAVE(1)	First independent variable
		9-10	ISAVE(2)	Second independent variable

Table D-2. Continued

Card Number	Card Format	Columns	Variable Name	Variable Description
15	2I2	1-2	NN	Number of different raw materials
		3-4	MM	Number of different sources for each raw material
16-a	18F4.0	1-4	DIST(1,1,1)	Distance from site 1 to source 1 for product 1
		5-8	DIST(1,1,2)	Distance from site 1 to source 1 for product 2
		⋮	⋮	⋮
		⋮	DIST(NXX,MM,NN)	Distance from site NXX to source MM for product NN
17-a	12F6.0	1-6	AMNT(1,1,1)	Amount of product 1 shipped to site 1 from source 1
		7-12	AMNT(1,1,2)	Amount of product 2 shipped to site 1 from source 1
		⋮	⋮	⋮
		⋮	AMNT(NXX,MM,NN)	Amount of product NN shipped to site NXX from source NN
18*, 19*, and 20*	(same as cards 12, 13-a, and 14-a)			
21	F10.0	1-10	VALUE	Estimated value of plant
22-a	6F10.2	1-10	CTAX(1)	Property tax mill levy at site 1
		11-20	CTAX(2)	Property tax mill levy at site 2
		⋮	⋮	⋮
		⋮	CTAX(NXX)	Property tax mill levy at site NXX
23	2F7.2	1-7	XLEVEL(1)	Amount of floor space needed for basement
		8-14	XLEVEL(2)	Amount of floor space needed for 1st floor

Table D-2. Continued

Card			Variable	
Number	Format	Columns	Name	Description
24-a	10F7.2	1-7	SQCOST(1,1)	Cost per square foot of level 1 at site 1
		8-14	SQCOST(1,2)	Cost per square foot of level 2 at site 1
		⋮	⋮	⋮
			SQCOST(NXX,3)	Cost per square foot of level 3 at site NXX
25	F10.4	1-10	CRF	Capital recovery factor
26	F10.0	1-10	USAGE	Amount of gas required
27	6I6	1-6	MCF(1)	Amount of gas for rate determination in classification 1
		7-12	MCF(2)	Amount of gas for rate determination in classification 2
		⋮	⋮	⋮
			MCF(6)	Amount of gas for rate determination in classification 6
28-a	18F4.2	1-4	RATE(1,1)	Gas rate for classification 1 at site 1
		5-8	RATE(1,2)	Gas rate for classification 2 at site 1
		⋮	⋮	⋮
			RATE(NXX,6)	Gas rate for classification 6 at site NXX
29	F10.0	1-10	AMOUNT	Amount of water required

Table D-2. Continued

Card			Variable	
Number	Format	Columns	Name	Description
30-31	10F7.0	1-7	S(1)	Amount of water for rate determination in classification 1
		8-14	S(2)	Amount of water for rate determination in classification 2
		:	:	:
		:	S(19)	Amount of water for rate determination in classification 19
32-a	14F5.2	1-5	BB(1,1)	Water rate for classification 1 at site 1
		6-10	BB(1,2)	Water rate for classification 2 at site 1
		:	:	:
		:	BB(NXX,19)	Water rate for classification 19 at site NXX

*These cards are valid only if the IBM regression routines [21] are used.

Program Print-Out

The plant location program was written in Fortran IV-H for the SDS Sigma 7 computer at Montana State University. With the exception of the regression routine, the entire program is listed in this section. The regression routine that was used for this study was obtained from the IBM Scientific Subroutine Package [12]. There were three modifications required to adapt the IBM routine to the plant location program:

1. In place of the statement,
```
    100 READ(5,1,END=400)PR,PR1,N,M,NS,
```
   in routine REGRES the following statements were inserted:
```
        NXX1=0
    100 NXX1=NXX1 + 1
        IF(NXX1 .EQ. 2) GO TO 300
        READ(5,1)PR,PR1,N,M,NS
```

2. In place of the END statement in routine REGRES the following statements were inserted:
```
        A1 = ANS(1)
        RETURN
        END
```

3. Between statements four and five in routine DATA the following statements were inserted:
```
        DO 2 I=1,M
      2 D(I) = ALOG(D(I))
```

The program listing that follows has the following characteristics:

1. At the beginning of each routine is a comment card describing the operation performed
2. Underneath the first comment card is the description of all variables appearing in each routine
3. The program uses mixed modes

```
C*****MAIN PROGRAM
C*****PLANT LOCATION
C*****FACI1(I)= TO THE OBJ. FACTOR MEASURE FOR SITE I.
C*****FACI2(I)= TO THE SUBJ. FACTOR MEASURE FOR SITE I.
C*****ROBJ=OBJECTIVE FACTOR DECISION WEIGHT.
C*****SUBJ=SUBJECTIVE FACTOR DECISION WEIGHT.
C*****FINAL(I)=TO THE LOCATION MEASURE FOR SITE I.
C*****FAKE(I)= TO A TERM USED TO ORDER THE LOCATION INDEXES.
C*****NBEST(I,J)=TO THE BEST LOCATION FOR OBJ. FACTOR
C*****                 DECISION WEIGHT I AND PRODUCTION RATE J.
      DIMENSION FINAL(50),FAKE(50),FACI1(50),FACI2(50)
      DIMENSION NBEST(11,5)
      COMMON NXX, FAC(50,49),FACI(50,14)
      INTEGER FAC
      READ(105,1) NXX
    1 FORMAT(I3)
      J1=0
   87 J1=J1+1
      NAP=25 + 25*J1
      IF(J1 .GT. 1) GO TO 89
      CALL SUBFAC(FACI2)
   89 CALL COST(FACI1,J1,NAP)
      WRITE(108,124)
  124 FORMAT(1H1,'*****FINAL ANALYSIS*****',//)
      DO 1000 JK=1,11
      ROBJ=(JK-1)*.1
      SUBJ=1.0-ROBJ
      DO 10 I=1,NXX
   10 FINAL(I)=ROBJ*FACI1(I)+SUBJ*FACI2(I)
      GO TO(68,68,68,67,68,68,67,68,68,67,68),JK
   68 WRITE(108,88) ROBJ
   88 FORMAT(/'OBJ. FACTOR DECISION WEIGHT =',2X,F4.2,/)
      GO TO 92
   67 WRITE(108,94) ROBJ
   94 FORMAT(1H1,'OBJ. FACTOR DECISION WEIGHT =',2X,F4.2,/)
   92 WRITE(108,90)
   90 FORMAT('SITE',10X,'LOCATION MEASURE',/)
      DO 40 JJ=1,NXX
      DO 30 I=1,NXX
      IF(I .EQ. 1) GO TO 28
      IF(FINAL(I) .LE. FAKE(JJ)) GO TO 30
   28 FAKE(JJ)=FINAL(I)
      MM=I
   30 CONTINUE
      IF(JJ.GT.1) GO TO 65
```

```
      NBEST(JK,J1)=MM
   65 WRITE(108,66) MM,FAKE(JJ)
   66 FORMAT(1X,I2,15X,F7.5)
      FINAL(MM)=-10.0
   40 CONTINUE
 1000 CONTINUE
      GO TO(87,87,87,87,80),J1
   80 WRITE(108,100)
  100 FORMAT(1H1,'OBJECTIVE FACTOR',10X,'PRODUCTION RATE')
      WRITE(108,101)
  101 FORMAT('DECISION WEIGHT',4X,'50%',4X,'75%',3X,'100%',
     13X,'125%',3X,'150%',/)
      DO 999 NX=1,11
      FOR=(NX-1)*.1
      WRITE(108,998) FOR,(NBEST(NX,NEX),NEX=1,5)
  998 FORMAT(6X,F5.2,8X,I2,5X,I2,5X,I2,5X,I2,5X,I2)
  999 CONTINUE
      END
```

```
      SUBROUTINE SUBFAC(FACI2)
C*****CALCULATES THE SUBJ. FACTOR MEASURE FOR EACH SITE.
C*****FROG(J)=TO THE WEIGHT OF SUBJECTIVE FACTOR J.
C*****FACI(I,J)= TO WEIGHT OF SITE I FOR FACTOR J.
C*****FACI2(I)= TO THE SUBJ. FACTOR MEASURE FOR SITE I.
      COMMON NXX, FAC(50,49),FACI(50,14)
      DIMENSION FROG(14),FACI2(50)
      CALL WEIGHT(FROG)
      DO 1 KK=1,14
      CALL SITEWT(FACI,KK)
    1 CONTINUE
      WRITE(108,15)
   15 FORMAT(1H1,'*****WEIGHTS OF SUBJECTIVE FACTORS AND',
     1' SITES*****',//)
      WRITE(108,20)
   20 FORMAT(1X,'SUBJECTIVE',8X,'SUBJECTIVE',8X,'SITE',8X,
     1'SITE')
      WRITE(108,21)
   21 FORMAT('FACTOR NUMBER',5X,'FACTOR WEIGHT',4X,
     1'NUMBER',4X,'WEIGHT')
      DO 35 J=1,14
      DO 30 I=1,NXX
      IF(I .GT. 1) GO TO 28
      WRITE(108,24) J,FROG(J),I,FACI(I,J)
   24 FORMAT(/,6X,I2,14X,F7.5,8X,I2,6X,F7.5)
      GO TO 30
   28 WRITE(108,29) I,FACI(I,J)
   29 FORMAT(37X,I2,6X,F7.5)
   30 CONTINUE
   35 CONTINUE
      DO 10 I=1,NXX
      FACI2(I)=0
      DO 5 J=1,14
    5 FACI2(I)=FROG(J)*FACI(I,J)+FACI2(I)
   10 CONTINUE
      WRITE(108,40)
   40 FORMAT(1H1,'*****SUBJECTIVE FACTOR MEASURE*****',///)
      WRITE(108,45)
   45 FORMAT('SITE',10X,'MEASURE',/)
      DO 68 I=1,NXX
      WRITE(108,67) I,FACI2(I)
   67 FORMAT(1X,I2,11X,F7.5)
   68 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE WEIGHT(FROG)
C*****CALCULATES SUBJECTIVE FACTOR WEIGHT.
C*****INDEX(I,J)=CONDENSED PREF. MATRIX FOR SUBJ. FACTORS.
C*****FROG(I)=THE WEIGHT ASSIGNED TO FACTOR I.
      DIMENSION INDEX(14,13),FROG(14)
      COMMON NXX
      READ(105,1) ((INDEX(I,J),J=1,13),I=1,14)
    1 FORMAT(13I2)
      SMOG=0
      DO 4 I=1,14
      FROG(I)=0
      DO 6 J=1,13
      FROG(I)=FROG(I)+INDEX(I,J)
    6 CONTINUE
      SMOG=SMOG+FROG(I)
    4 CONTINUE
      DO 12 I=1,14
      FROG(I)=FROG(I)/SMOG
   12 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SITEWT(FACI,KK)
C*****CALCULATES THE SITE WEIGHT FOR EACH SUBJ. FACTOR.
C*****FAC(I,J)=CONDENSED PREFERENCE MATRIX FOR FACTOR KK.
C*****FACI(I,KK)=TO WEIGHT OF SITE I FOR FACTOR KK.
C*****THE RELATIONSHIP BETWEEN THE SUBJ. FACTORS AND KK IS;
C******KK-        -FACTOR-
C****** 1-        AVAILABILITY OF TRANSPORTATION
C****** 2-        INDUSTRIAL SITES
C****** 3-        CLIMATE
C****** 4-        EDUCATION FACILITIES
C****** 5-        UNIONS
C****** 6-        RECREATIONAL FACILITIES
C****** 7-        HOUSING
C****** 8-        FUTURE GROWTH
C****** 9-        COMMUNITY SERVICES
C******-10-       EMPLOYEE TRANSPORTATION FACILITIES
C******-11-       COST OF LIVING
C******-12-       COMPETITION
C******-13-       COMPLEMENTARY INDUSTRIES
C******-14-       AVAILABILITY OF LABOR
      COMMON NXX, FAC(50,49)
      DIMENSION FACI(50,14)
      INTEGER FAC
      NOX=NXX-1
      READ(105,1) ((FAC(I,J),J=1,NOX),I=1,NXX)
    1 FORMAT(30I2)
      SUM=0
      DO 6 I=1,NXX
      FACI(I,KK)=0
      DO 5 J=1,NOX
    5 FACI(I,KK)=FACI(I,KK)+FAC(I,J)
    6 SUM=SUM+FACI(I,KK)
      DO 7 I=1,NXX
    7 FACI(I,KK)=FACI(I,KK)/SUM
      RETURN
      END
```

```
      SUBROUTINE COST(FACI1,J1,NAP)
C*****CALCULATES THE OBJECTIVE FACTOR MEASURE FOR EACH SITE.
C*****FCOST(I)=OBJECTIVE FACTOR COST OF SITE I.
C*****FACI1(I)=OBJECTIVE FACTOR MEASURE OF SITE I
      DIMENSION FCOST(50),FACI1(50),LIX1(50),TRANS(50)
      DIMENSION BUCOST(50),WCOST(50),TAX(50),LAB(50)
      DIMENSION GAS(50)
      COMMON NXX
      REAL LAB,LIX1
      CALL LABOR(LAB,J1,NAP)
      CALL MARKET(LIX1,J1,NAP)
      CALL RAWM(TRANS,J1,NAP)
      IF(J1 .GT. 1) GO TO 20
      CALL TAXES(TAX)
      CALL BUILD(BUCOST)
      CALL UTIL(GAS)
      CALL WATER(WCOST)
   20 FSUM=0
      DO 5 I=1,NXX
      I1=TRANS(I)+.5
      I2=GAS(I)+.5
      I3=LIX1(I)+.5
      I4=BUCOST(I)+.5
      I5=WCOST(I)+.5
      I6=TAX(I)+.5
      I7=LAB(I)+.5
      FCOST(I)=I1+I2+I3+I4+I5+I6+I7
      FSUM=FSUM+FCOST(I)
    5 CONTINUE
      WRITE(108,9)
    9 FORMAT(//,'*****COST OF OBJECTIVE FACTORS*****'//)
      WRITE(108,10)
   10 FORMAT(16X,'SITE 1',5X,'SITE 2',5X,'SITE 3',5X,
     1'SITE 4',5X,'SITE 5',5X,'SITE 6',/)
      NOT=1
      NOP=NXX
   54 WRITE(108,11) (WCOST(I),I=NOT,NOP)
   11 FORMAT('WATER',11X,F6.0,5X,F6.0,5X,F6.0,5X,F6.0,5X,
     1F6.0,5X,F6.0)
      WRITE(108,12) (LAB(I),I=NOT,NOP)
```

```
12 FORMAT('LABOR',11X,F6.0,5X,F6.0,5X,F6.0,5X,F6.0,5X,
  1F6.0,5X,F6.0)
   WRITE(108,13) (TAX(I),I=NOT,NOP)
13 FORMAT('TAXES',11X,F6.0,5X,F6.0,5X,F6.0,5X,F6.0,5X,
  1F6.0,5X,F6.0)
   WRITE(108,14) (BUCOST(I),I=NOT,NOP)
14 FORMAT('BUILD',11X,F6.0,5X,F6.0,5X,F6.0,5X,F6.0,5X,
  1F6.0,5X,F6.0)
   WRITE(108,16) (LIX1(I),I=NOT,NOP)
16 FORMAT('MARKET',10X,F6.0,5X,F6.0,5X,F6.0,5X,F6.0,5X,
  1F6.0,5X,F6.0)
   WRITE(108,17) (TRANS(I),I=NOT,NOP)
17 FORMAT('RAW MATL',8X,F6.0,5X,F6.0,5X,F6.0,5X,F6.0,
  15X,F6.0,5X,F6.0)
   WRITE(108,19) (GAS(I),I=NOT,NOP)
19 FORMAT('GAS',13X,F6.0,5X,F6.0,5X,F6.0,5X,F6.0,5X,
  1F6.0,5X,F6.0)
   WRITE(108,18) (FCOST(I),I=NOT,NOP)
18 FORMAT(/,'TOTAL COST',6X,F6.0,5X,F6.0,5X,F6.0,5X,
  1F6.0,5X,F6.0,5X,F6.0)
   RSUM=0
   DO 15 I=1,NXX
   RSUM=RSUM+(FSUM/FCOST(I))
15 CONTINUE
   WRITE(108,65)
65 FORMAT(1H1,'*****OBJECTIVE FACTOR MEASURE*****'////)
   WRITE(108,66)
66 FORMAT('SITE',10X,'MEASURE',/)
   DO 7 I=1,NXX
   FACI1(I)=(FSUM/FCOST(I))/RSUM
   WRITE(108,67) I,FACI1(I)
67 FORMAT(1X,I2,11X,F7.5)
 7 CONTINUE
   RETURN
   END
```

```
      SUBROUTINE LABOR(LAB,J1,NAP)
C*****COST OF LABOR
C*****NHR=NUMBER OF DIFFERENT TYPES OF HOURLY PAID WORKERS.
C*****MO=NUMBER OF DIFFERENT TYPES OF MONTHLY PAID WORKERS.
C*****CHR(I,J)=COST PER HOUR OF TYPE J WORKER AT SITE I.
C*****CMO(I,J)=COST PER MONTH OF TYPE J WORKER AT SITE I.
C*****NUM1(J)=NUMBER OF TYPE J HOURLY WORKERS NEEDED.
C*****NUM2(J)=NUMBER OF TYPE J MONTHLY WORKERS NEEDED.
C*****TCHR(I)=TOTAL COST OF HOURLY WORKERS AT SITE I.
C*****TCMO(I)=TOTAL COST OF MONTHLY WORKERS AT SITE I.
C*****LAB(I)=COST OF LABOR AT SITE I.
      DIMENSION CHR(50,10),CMO(50,10),NUM1(10),NUM2(10)
      DIMENSION TCHR(50),TCMO(50),LAB(50),NB(10),NC(10)
      COMMON NXX
      REAL LAB,NB,NC
      IF(J1 .GT. 1) GO TO 20
      READ(105,10) NHR,MO
   10 FORMAT(2I3)
      READ(105,15) ((CHR(I,J),J=1,NHR),I=1,NXX)
   15 FORMAT(12F5.2)
      READ(105,25) ((CMO(I,J),J=1,MO),I=1,NXX)
   25 FORMAT(15F4.0)
      READ(105,30) (NUM1(J),J=1,NHR)
   30 FORMAT(20I3)
      READ(105,35) (NUM2(J),J=1,MO)
   35 FORMAT(20I3)
   20 DO 310 I=1,NXX
      TCHR(I)=0
      TCMO(I)=0
      DO 300 J=1,NHR
      NB(J)=NUM1(J)*(NAP*0.01)
  300 TCHR(I)=TCHR(I)+(NB(J)*CHR(I,J)*173)
      DO 302 J=1,MO
      NC(J)=NUM2(J)*(NAP*0.01)
      IF(J .EQ. 2) NC(J)=1
  302 TCMO(I)=TCMO(I)+(NC(J)*CMO(I,J))
  310 LAB(I)=TCMO(I)+TCHR(I)
      RETURN
      END
```

```
      SUBROUTINE MARKET(LIX1,J1,NAP)
C*****CALCULATES THE COST OF MARKETING.
C*****VOLUME=TOTAL AMOUNT OF PRODUCTS SHIPPED.
C*****IN=NUMBER OF MARKETS
C*****IM=NUMBER OF DIFFERENT PRODUCTS TO BE SHIPPED.
C*****DIST(I,J)= THE DISTANCE FROM I TO J.
C*****SALES(J,K)=THE SALES OF ITEM K AT MARKET J.
C*****A(K)=REGRESSION CONSTANT FOR PRODUCT K.
C*****BB(K,1)=REGRESSION EXPONENT FOR DIST. AND PRODUCT K.
C*****BB(K,2)=REGRESSION EXPONENT FOR WEIGHT AND PRODUCT K.
C*****LIX(I,K)=MARKETING COST FOR SITE I AND PRODUCT K.
C*****LIX1(I)=MARKETING COST FOR SITE I.
      DIMENSION A(10),BB(10,2),LIX(50,10)
      DIMENSION DIST(50,100),SALES(100,10),B(40),LIX1(50)
      COMMON NXX
      REAL LIX1
      IF(J1 .GT. 1) GO TO 60
      READ(105,2) VOLUME,IN,IM
    2 FORMAT(F10.2,2I4)
      READ(105,1) ((DIST(I,J),J=1,IN),I=1,NXX)
    1 FORMAT(18F4.0)
      READ(105,4) ((SALES(I,J),J=1,IM),I=1,IN)
    4 FORMAT(12F6.0)
      DO 100 K=1,IM
      CALL REGRES(A1,B)
      A(K)=EXP(A1)
      BB(K,1)=B(1)
      BB(K,2)=B(2)
  100 CONTINUE
   60 DO 110 K=1,IM
      DO 10 I=1,NXX
      LIX(I,K)=0
      DO 8 J=1,IN
      ASALES=(NAP*.01)*SALES(J,K)
      HAM=ASALES**BB(K,2)
      SAM=DIST(I,J)**BB(K,1)
      LIX(I,K)=A(K)*HAM*SAM+LIX(I,K)
    8 CONTINUE
   10 CONTINUE
  110 CONTINUE
      DO 17 I=1,NXX
      LIX1(I)=0
      DO 16 K=1,IM
      LIX1(I)=LIX1(I)+LIX(I,K)
   16 CONTINUE
   17 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE RAWM(TRANS,J1,NAP)
C*****CALCULATES THE COST OF RAW MATERIALS.
C*****NN=NUMBER OF DIFFERENT RAW MATERIALS REQUIRED.
C*****MM=NUMBER OF SOURCES FOR EACH RAW MATERIAL.
C*****DIST(I,J)=THE DISTANCE FROM SITE I TO MARKET J.
C*****AMNT(I,J,K)=AMOUNT OF MATERIAL K TO BE SHIPPED FROM
C*****             J TO I AT A PRODUCTION RATE OF 100%.
C*****AMNT1(I,J,K)=AMOUNT OF MATERIAL K TO BE SHIPPED FROM
C*****              J TO I AT VARIOUS PRODUCTION RATES.
C*****A(K)=REGRESSION CONSTANT FOR RAW MATERIAL K.
C*****BB(K,1)=REGRESSION EXPONENT FOR DIST. AND RAW MAT. K.
C*****BB(K,2)=REGRESSION EXPONENT FOR WT. AND RAW MAT. K.
C*****TCOST(I,K)=MIN COST FOR MATERIAL K AT SITE I.
C*****TRAN(I,J,K)=COST OF SHIPPING MATERIAL K FROM J TO I.
C*****TRANS(I)=COST OF TRANSPORTING RAW MATERIAL TO SITE I.
      DIMENSION AMNT1(50,5,10),TCOST(50,10),B(40),A(10)
      DIMENSION BB(10,2),DIST(50,5,10)
      DIMENSION TRANS(50),AMNT(50,5,10),TRAN(50,5,10)
      COMMON NXX
      IF(J1 .GT. 1) GO TO 60
      READ(105,6) NN,MM
    6 FORMAT(2I2)
      READ(105,7) (((DIST(I,J,K),K=1,NN),J=1,MM),I=1,NXX)
    7 FORMAT(18F4.0)
      READ(105,8) (((AMNT(I,J,K),K=1,NN),J=1,MM),I=1,NXX)
    8 FORMAT(12F6.0)
      DO 10 K=1,NN
      CALL REGRES(A1,B)
      A(K)=EXP(A1)
      BB(K,1)=B(1)
      BB(K,2)=B(2)
   10 CONTINUE
   60 WRITE(108,97)
   97 FORMAT(1H1,'*****************************************')
      WRITE(108,98) NAP
   98 FORMAT('*',1X,'PRODUCTION RATE EQUALS',I4,2X,
     1'PERCENT',1X,'*')
      WRITE(108,99)
   99 FORMAT('*****************************************',//)
      WRITE(108,36)
```

```
36 FORMAT('*****SOURCE OF RAW MATERIALS*****',//)
   DO 12 K=1,NN
   DO 5 I=1,NXX
   DO 2 J=1,MM
   AMNT1(I,J,K)=(NAP*.01)*AMNT(I,J,K)
   DUMMY=AMNT1(I,J,K)**BB(K,2)
   TRAN(I,J,K)=A(K)*(DIST(I,J,K)**BB(K,1))*DUMMY
   IF(J .EQ. 1) GO TO 25
   IF(TRAN(I,J,K) .GE. TRAN(I,J-1,K)) GO TO 2
25 TCOST(I,K)=TRAN(I,J,K)
   MIN=J
 2 CONTINUE
   WRITE(108,22) K,MIN,I
22 FORMAT('BUY PRODUCT',I2,'FROM SUPPLIER',
  1I2,' AT SITE',I2)
 5 CONTINUE
12 CONTINUE
   DO 30 I=1,NXX
   TRANS(I)=0
   DO 28 K=1,NN
   TRANS(I)=TCOST(I,K)+TRANS(I)
28 CONTINUE
30 CONTINUE
   RETURN
   END
```

```
      SUBROUTINE TAXES(TAX)
C*****COST OF PROPERTY TAX.
C*****CTAX(I)=PROPERTY TAX MILL LEVY AT SITE I.
C*****TAX(I)=TOTAL TAX CHARGE AT I.
C*****VALUE=ESTIMATED VALUE OF THE PLANT.
      DIMENSION CTAX(50),TAX(50)
      COMMON NXX
      READ(105,1) VALUE
    1 FORMAT(F10.1)
      READ(105,2) (CTAX(I),I=1,NXX)
    2 FORMAT(6F10.2)
      DO 3 I=1,NXX
    3 TAX(I)=(CTAX(I)*VALUE*.40)/12000
      RETURN
      END
```

```
      SUBROUTINE BUILD(BUCOST)
C*****COST OF BUILDING.
C*****XLEVEL(K)=AMOUNT OF FLOOR SPACE NEEDED AT LEVEL K
C*****K=1,BASEMENT;2,GROUND FLOOR;3,2OND FLOOR.
C*****SQCOST(I,K)=COST OF LEVEL K AT CENTER I
C*****CRF=CAPITAL RECOVERY FACTOR FOR 20 YRS & INT.=10%.
C*****BUCOST(I)=BUILDING COST AT CENTER I.
      DIMENSION SQCOST(50,3),XLEVEL(3),BUCOST(50)
      COMMON NXX
      READ(105,2) (XLEVEL(K),K=1,3)
    2 FORMAT(3F7.2)
      READ(105,4) ((SQCOST(I,K),K=1,3),I=1,NXX)
    4 FORMAT(10F7.2)
      READ(105,5) CRF
    5 FORMAT(F10.4)
   20 DO 10 I=1,NXX
      BUCOST(I)=0
      DO 8 K=1,3
      BUCOST(I)=BUCOST(I)+SQCOST(I,K)*XLEVEL(K)
    8 CONTINUE
      BUCOST(I)=(BUCOST(I)*CRF)/12
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE UTIL(GAS)
C*****COST OF GAS
C*****USAGE=AMOUNT OF GAS NEEDED.
C*****MCF(J)=THE J DIFFERENT GAS CATEGORIES.
C*****RATE(I,J)=COST OF CATEGORY J AT I.
C*****GAS(I)=COST OF GAS AT I.
      DIMENSION MCF(6),RATE(50,6),GAS(50)
      COMMON NXX
      READ(105,1) USAGE
    1 FORMAT(F10.0)
      READ(105,2) (MCF(J),J=1,6)
    2 FORMAT(6I6)
      READ(105,3) (( RATE(I,J),J=1,6),I=1,NXX)
    3 FORMAT(18F4.2)
      DO 10 I=1,NXX
      AMOUNT=USAGE
      GAS(I)=0
      DO 8 J=1,6
      IF(AMOUNT .LT. MCF(J)) GO TO 7
      GAS(I)=GAS(I)+RATE(I,J)*MCF(J)
      AMOUNT=AMOUNT-MCF(J)
      GO TO 8
    7 GAS(I)=GAS(I)+RATE(I,J)*AMOUNT
      GO TO 10
    8 CONTINUE
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE WATER(WCOST)
C*****COST OF WATER.
C*****WCOST(I)=COST OF WATER AND SEWER AT SITE I.
C*****BB(I,J)=COST AT CENTER I FOR AMOUNT J.
C*****AMOUNT=REQUIRED WATER SUPPLY NEEDED PER MONTH
C*****S(J)=THE J DIFFERENT WATER AND SEWER CATEGORIES.
      DIMENSION BB(50,19),WCOST(50),S(19)
      COMMON NXX
      READ(105,6) AMOUNT
    6 FORMAT(F10.0)
      READ(105,4) (S(J),J=1,19)
    4 FORMAT(10F7.0)
      READ(105,2) ((BB(I,J),J=1,19),I=1,NXX)
    2 FORMAT(14F5.2)
      DO 10 I=1,NXX
      CUFT=AMOUNT
      WCOST(I)=0
      DO 8 J=1,19
      IF(CUFT .LT. S(J)) GO TO 7
      WCOST(I)=WCOST(I)+BB(I,J)*S(J)
      CUFT=CUFT-S(J)
      GO TO 8
    7 WCOST(I)=WCOST(I)+BB(I,J)*CUFT
      GO TO 10
    8 CONTINUE
   10 CONTINUE
      RETURN
      END
```

VITA

Phillip Argene Brown was born in Evansville, Indiana, on June 21, 1942. Mr. Brown and his parents, Mr. and Mrs. Argene R. Brown, later moved to Hobbs, New Mexico, where he completed his secondary education at Hobbs High School in June of 1960. His formal education was obtained from Texas Tech University where he earned a Bachelor of Science Degree in Industrial Engineering. Among his scholastic achievements are membership in Alpha Pi Mu, Industrial Engineering Honorary Fraternity, and the Dean's Honor Roll at Texas Tech University.