A METHOD FOR EVALUATING INDUSTRIAL LOCATION ALTERNATIVES

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by

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ABSTRACT

The problem of choosing a location for an industry is complex and far-reaching in its consequences. Pure location theory attempts to explain existing spatial patterns by adopting simplifying assumptions to reduce the complexity. It does not offer a method for evaluating alternative locations.

Such a method is developed based on the locational variance of cost factors and the relative size of cost factors in the cost structure of the industry. An exact mathematical relationship is presented for assigning weight to a location factor based on its contribution to the total locational variance of costs.

$$W_i = C_i \cdot \frac{\sigma_i}{\sum_{i=1}^{n} \sigma_i}$$

Where W_i is the weight for factor i
C_i is the expected annual cost for factor i at a specific location.
σ_i is the contribution of factor i to total locational variance.
$\sum_{i=1}^{n} \sigma_i$ is the total locational variance.

A method for evaluating intangible and purely personal factors is suggested and illustrated. Least cost locations

are determined by an analysis of locational variance. Location alternatives are further evaluated by taking demand or market considerations into account. Conventional methods such as market forecasting and analysis of fixed and variable costs over the minimum planning horizon of fifteen years are used to contrast alternative locations. Uncertainty in demand estimates arising from imperfect information is approached using decision theory and expected value criteria.

The regional problem in which a region is seeking or evaluating prospective industries is seen as the mirror image of the location problem. Regions should evaluate prospective industry in a rigorous manner to ensure that new industry is socially and environmentally acceptable and economically feasible. Such regional evaluation would reduce the likelihood of major industrial failures with their attendant social and economic ill effects.

The method presented is easily comprehended, practical and rigorous. It is felt that use of this method will reduce the speculative element in evaluating location alternatives or prospective industries. In this way location decisions are put on a factual basis and analysed within the framework of the balance sheet.

FOREWORD

This paper was prepared in partial fulfillment of the requirements for the degree of Master of Engineering at Memorial University of Newfoundland. Initial interest in the problem of locating industries arose from assisting Professor T.W. Kierans, Faculty of Engineering, in his role as Chairman of an American Society of Civil Engineers Siting Committee. This committee was charged with preparing a document on Siting for the Manual of Standard Practice on Nuclear Structures and Materials.

The purpose of the paper is to provide a practical but rigorous method for evaluating location alternatives from the points of view of the individual firm and the developing region. The emphasis is placed on a stepwise procedure that permits quantification of location factors and operates in the framework of the balance sheet. Historical trends in location theory are used to develop such a method.

The assistance of Professor Kierans, who supervised this research, is greatfully acknowledged. The help of Professor Roger Hayter, now with the Department of Geography, Simon Fraser University and formerly of the Department of Geography, Memorial University of Newfoundland, is also acknowledged. The support of Memorial University's Division of Co-ordination is very much appreciated. Special thanks are due Denise Collins who typed and retyped the paper at all stages of revision.

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INTRODUCTION

The problem of locating an industrial facility has received less than its fair share of analytical attention in engineering literature. While great strides have been taken in related areas such as the allocation of resources within facilities and networks, the larger problem of plant location remains a complex issue often ignored entirely but usually approached on least cost criteria. This is inadequate because least cost locations are not necessarily locations where profit maximization will occur. Further, least cost models do not consider plant interdependence and market dynamics.

The importance of location decisions is easily established by consideration of the permanence, high costs and social aspects inherent in such decisions. A plant, once located, represents a considerable investment that is permanently fixed. It cannot be moved to a more desirable location as can a poorly located machine. Thus, the fixed costs associated with a poor location decision will never be fully recovered and may lead to failure of the enterprise. The permanence of a located plant is often overlooked in normative location theory. In addition to the problems poor location decisions cause for the firm, there are the equally devastating effects on the community and the employees of the venture.

Some researchers report productivity differentials of up to 20% based on regional differences.[1] It is clear that geographic location has a varying but definite impact on cost factors such as labour, transport, energy and taxes. It also has an influence on morale and efficiency. This is usually considered intangible but with some manipulation can be translated into cost effects. Entrepreneurs would like to know, as closely as possible, how costs will vary with location, before taking a decision; firms already located may want to find out if it is worth changing locations in order to reduce locational costs, expand sales or otherwise optimize regional economies. A straightforward, analytical method that operates within the framework of the balance sheet is not available for this problem.

This is not to say that researchers have ignored the location problem although only in recent years have economic geographers and regional scientists focused their attention on this subject with any intensity. The diverse social and economic problems of urban centres and developing regions have given rise to increased interest in plant location. Today the literature includes contributions from geographers, economists, sociologists, planners, mathematicians, engineers and other fields of endeavour. Significant growth in location theory literature has been experienced in the last 20 years.

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[1] Sten Soderman, Industrial Location Planning, 1975, Chapter 1.

Interesting departures have been made from the historical trend in location theory and pursued relentlessly by avid researchers. Although the main body of research is singularly oriented, it is far from unified. A universally accepted normative theory has not evolved and empirical studies are often at odds with theoretical work, even when carried out by the same researcher. Söderman reports that after formulating a normative model, he attempted to collect data with the idea of proving its applicability. "The attempt was frustrating. The assumptions of the model were supported to only a very limited extent."[1]

The lack of conformance between theory and practice has bothered many researchers who have sought to develop a normative theory. It is partially explained by the importance of personal preference in location decisions and partially by the manager's tendency to rely on hunch and intuition when faced with a complex decision for which he has no analytical method. A point often overlooked is that regardless of what reasons a manager may have had for choosing a location, it may still be a good location, or more likely, a location which will permit successful operation but prevent maximum profits. If rigorous, but practical methods were available for evaluating alternative locations, greater agreement between theory and practice would likely result. The

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[1]Sten Söderman, Industrial Location Planning, 1975, p. vii.

purpose of this paper is to provide one such method.

It is therefore not an attempt to build on location theory; rather it is an attempt to draw from location theory the elements necessary to develop an evaluative method for the individual firm faced with making a locational decision. Undoubtedly other methods will be developed; hopefully new approaches to this important problem will come along. Until then, the various theories of location provide the richest source of material from which to draw. The problem is approached from an engineering point of view where the emphasis is on making the best decision, within specified time constraints, by drawing on whatever resources are available.

Location decisions are far reaching in their consequences, complex in nature and taken infrequently by an individual firm. For these reasons it is felt that a method which pursues its objective by breaking the decision process down into small but well defined steps, that can each be evaluated as the method is applied, will be most effective. In this respect the method is not final decision oriented, but it is sensitive to the inputs being evaluated at all preliminary and intermediate steps in the process. Naturally a final decision is reached, but at no time during the pursuit of this decision does the method lose sight of the complex process it is attempting to quantify.

Because the background for this work was a study of location theory proper as well as some empiricial studies and accounts of locational decisions, Part I of this paper will deal with the historical development of location theory. In this way it will become clear which cost factors are important, how personal considerations have been dealt with and to what extent models reflect reality. The important contributions of most major researchers will be outlined. While this will not be a complete treatment it will serve as an introduction for a reader new to the subject and as a review for others.

Part II develops a method of making plant location decisions based on the locational variance of cost factors, the relative importance of these factors and the expected output at each location. Part III discusses extensions and variations of the basic method.

The objective of location theory is to explain the spatial distribution of man's activities. Under this broad heading comes the formation of towns and cities, the clustering of industries and the shifting patterns of populations. Because of the great variety of industries and the numerous complexities involved in the location process, theorists have sought to reduce the problem to sizeable proportions by adopting simplifying assumptions. The extent to which these assumptions are justified and can be dropped when moving to reality without substantially altering the predictions of the theory, predetermines the effectiveness of the theory. Even the most careful reasoning and calculations when based on weak or unjustified assumptions will amount to little.

PART I

HISTORY OF LOCATION THEORY

Chapter I

Early Land Use Models

1.1 Ricardo

Perhaps the earliest attempt to explain location patterns was that of Ricardo[1], an English economist writing in the early nineteen hundreds. Although Ricardo was not primarily interested in developing a theory of location, he found that his major objective of explaining how wages, profits and rents are distributed in an agrarian society required an explanation of land use. Ricardo assumed that only one crop, corn, was to be grown. Land was limited in quantity and fertility was variable. The variation in fertility along with distance from the market determined the quality of land. Thus, land of inferior fertility required more labour to produce a unit of corn. The fertile, or better located land, produced more corn for the same labour input and this could be considered as land rent.

Ricardo's equating of market distance and fertility

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[1] David Ricardo, Principles of Political Economy and Taxation, 1919.

of soil obscured the significance of distance and location in land use analysis. His critics have argued that land cannot be consistently ordered according to quality in this sense when there is no inherent relation between distance and fertility. Palander points out that Ricardo's confusion in this matter was detrimental to the development of a meaningful location and land use theory among English speaking economists.[1]

1.2 von Thünen

Of much more importance was the work of von Thünen, a German agriculturalist who set out to develop a theory of land rent.[2] The influence of von Thünen on the development of location theory in German literature is pronounced and it is unfortunate that his work did not become widely known through translation. Indeed, it is difficult even today to obtain a translation of von Thünen's original work; this analysis is based on the best summaries and edited versions available.[3,4,5] Von Thünen is credited with having

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[1]T. Palander, Beiträge zur Standortstheorie, 1935, pp. 66-70.

[2]Johann Heinrich von Thünen, Der Isolierte Staat in Beziehung auf Landwirtschaft und Nationalokonomie, 3rd ed., 1875.

[3]Jean H. Paelinek and Peter Nijkamp, Operational Theory and Method in Regional Economics, 1975.

[4]Michael J. Webber, Impact of Uncertainty on Location, 1972.

[5]P. Hall, ed., von Thünen's Isolated State, 1966.

provided the basis of agricultural location theory. While this may be true, it ignores the general applicability of his work to the industrial situation. This was observed by Greenhut." .... his theory can be converted into an analysis of the site-selections of manufacturing plants....rather than enquire into the type of product cultivated at a given site, the enquiry can be directed toward ascertaining the location of a given manufacturing process."[1]

Von Thünen wanted to explore the relationship between a town, which manufactured goods, and the surrounding countryside, which provided agricultural produce. In particular, he wished to determine the optimal use pattern for agricultural land. He presented the problem as follows;

> Imagine a very large town, at the centre of a fertile plain which is crossed by no navigable river or canal. Throughout the plain the soil is capable of cultivation and of the same fertility. Far from the town, the plain turns into an uncultivated wilderness which cuts off all communication between this State and the outside world.... There are no other towns on the plain. The central town must therefore supply the rural areas with all manufactured products, and in return, it will obtain all its provisions from the surrounding countryside....The problem we want to solve is this: What pattern of cultivation will take shape in these conditions?; and how will the farming system of the different districts be affected by their distance from the town?[2]

A number of assumptions are implicit in von Thünen's theory but they were not formally set down. They are:

1) A completely homogeneous plain.

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[1]Melvin L. Greenhut, Plant Location in Theory and in Practice, 1956, p. 6.

[2]Von Thünen, P.Hall ed. and trans; von Thünen's Isolated State, 1966, pp. 11-12.

2) The town or market is a point containing resources, e.g. coal and iron.

3) The only use of land is agricultural and land owners attempt to maximize profits.

4) Labour is mobile and no real wage differences exist, ie. uniform productivity; actual differences appear as land rent.

5) Methods of cultivation are everywhere the same and land owners have no advantages over one another other than distance from the central market.

6) All prices in the market are fixed and known.

7) The unit cost of transportation for all crops is fixed and known and expressed in terms of one particular crop (rye).

8) No differentiated production stages exist and hence no industrial linkages.

9) Capital is perfectly mobile.

Von Thünen's chief findings were that the rent of land increased as distance from the town decreased and that land use patterns developed in the shape of concentric circles around the town. For a specific crop, rent is maximized if production takes place up to that distance from town at which marginal costs equal marginal returns. For two different crops (at the same distance from town) an opportunity cost arises which takes the form of land rent. Since market prices and transport rates are fixed, rent is a function of location.

Following the treatment of Webber[1] the following analysis shows how the model can be built.

$$R = E\ (p - a) - E \cdot f \cdot K \quad \text{- - - - Equation 1}$$

Where R is unit rent of land, E is unit yield of land, p is unit market price of the good, a is unit production cost of the good and f is the transport rate per unit of distance. This relationship is shown in Figure 1 below.

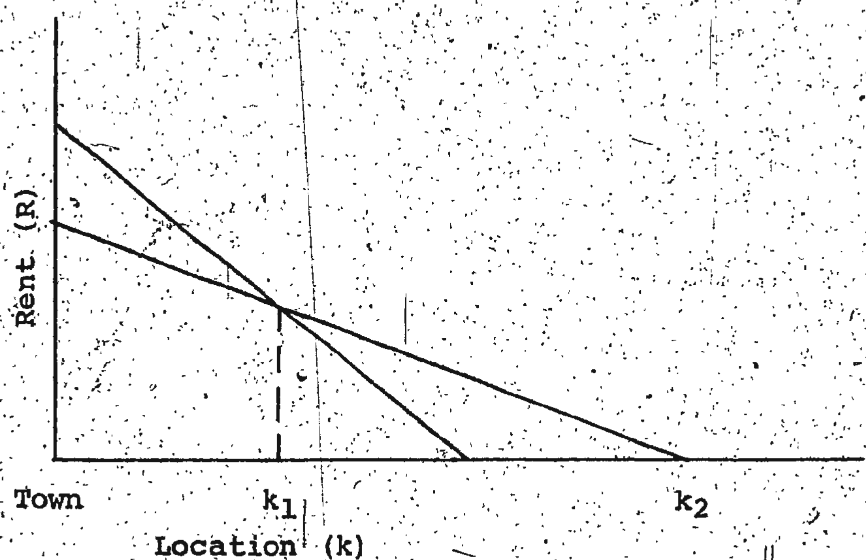

Figure 1 - Rent Curves for two crops

The sloping lines are lines of marginal rents. From centre of town to location k_1 it will be more profitable to cultivate crop 1. From k_1 to k_2 rents will be maximized if crop 2 is cultivated.

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[1]Webber, Impact of Uncertainty on Location, Chapter 3.

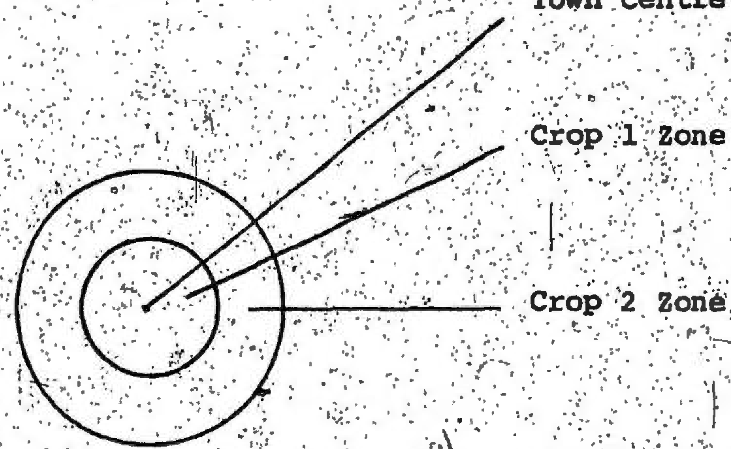

Figure 2 - Concentric Land use zones

It is easy to see that concentric zones of land use are predicted by this model. These are shown in Figure 2 above.

Although graphically simple, at least for two crops, a mathematical determination is difficult. The problem as formulated, however, is amenable to linear programming. Linear programmes have been developed[1] and where applied have been partially verified by empirical results. The problems encountered by linear programming models are reflections of the high levels of distortion (non-linearity)

[1] Ibid., pp. 52-56.

in transport costs and fertility. In addition, economies and diseconomies of scale cannot be accounted for in a linear model. In practice, these forces generate competing centres which affect the central market and hence the prices. These spatial distortions and scale economies are not consistent with the assumptions on which von Thünen's theory is based and therefore it is not surprising that land use models based on distance from the central market do not closely reflect reality.

In modern applications such as transportation planning and urban development, where land prices are considered a function of the distance from the city's centre, modified linear land use models have been developed.[1]

Von Thünen's work was of major importance in location theory development, but it is obvious that some of his simplifying assumptions weakened the theory. Perhaps most important, his assumption of one centre with fixed prices ruled out interdependence of industries based on the demand function. It has also been argued that considering the market as a point with no area is not realistic. Market analysis uses the opposite approach where production takes place at a point and the market has spatial dimensions.

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[1]See, for example, W. Alonso, Location and Land Use, Toward a General Theory of Land Rent., 1964.

Chapter 2

Industrial Location Models

2.1 Weber

Alfred Weber, who is today regarded as the founder of location theory, wrote his major treatise in 1909.[1] Although less penetrating in his analysis than von Thünen, Weber has had a major influence on the development of location theory. This can be traced to two main causes: First and perhaps most important, Weber's work was translated to English as early as 1929.[2] Secondly, Weber was an economist addressing an industrial phenomenon. These two facts taken together account for the wide coverage and important influence that Weber's theory exerted upon early German, British, American and French economists who studied the location problem. Weber had the effect of generating interest in the subject and his influence is still much in evidence today. It should be pointed out that Weber's theory is based on an earlier

[1] Alfred Weber, Uber Den Standort der Industrien, 1909.

[2] C.J. Friedrich, trans, and ed; Alfred Weber's Theory of the Location of Industries, 1929; Friedrich's translation is henceforth referred to as Weber's Theory of the Location of Industries.

writing by Launhardt published in 1885.[1]

Weber's objective was to develop a general or *pure* theory of location. To this end he classified locational factors as general or special. Locational factor is defined as "... an advantage which is gained when an economic activity takes place at a particular point or at several such points rather then elsewhere."[2] Although Weber devotes several chapters to the distinctions between general and special factors, he never does succeed in clarifying the issue. In the final analysis, he considers transportation, labour and agglomeration[3]/deglomeration forces as general factors which must be considered for every industry. Other factors including climate, cost of capital, personal preference, insurance, taxes, cost of land and buildings are not considered. Power and raw material differences have the effect of translating the deposits nearer or farther from the point of consumption; hence they affect the cost of transportation rather than acting as independent factors.

In effect, this meant that Weber considered only

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[1] W. Launhardt, Mathematische Begrundung der Volkswirtschaftalehre, 1885.

[2] Weber, Theory of the Location of Industries, p. 18.

[3] Forces which act to concentrate or disperse industry such as communication and rent.

three variables - transportation, labour and agglomeration forces. In addition to these general provisions, the following simplifying assumptions were made:[1]

1) The location of raw materials is given

2) The location and size of the consumming centres are given. Prices are fixed.

3) Labour is immobile and unlimited; wages in any given locality are fixed but not necessarily equal to those of another locality.

Although these assumptions were stated explicitly, Weber made several implicit assumptions which should also be noted. These are:

1) Only one firm is considered, all others having located previously.

2) A given quantity of a specific product is produced.

3) Transportation costs are uniform and known.

4) Production costs are fixed i.e. known production coefficients.

5) A locating firm seeks to minimize transportation costs.

Weber classified industries as materials, market or labour oriented and, for each industry, determined a material index (M.I.) defined as the ratio of the weight of localized materials to the weight of finished product.[2]

$$MI = \frac{\text{Weight of localized materials}}{\text{Weight of finished product}}$$

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[1]Weber, Theory of the Location of Industries, Chapter II.

[2]Ibid, Chapter III.

He then postulated the formation of a polygon whose sides would be proportional to the distances between raw materials deposits and the consumption centre. In the case of two raw materials, this would become a triangle. The material indexes act as forces operating on the optimal location and pulling it toward that particular raw material with a force porportional to the size of the materials index. This is illustrated in Figure 3

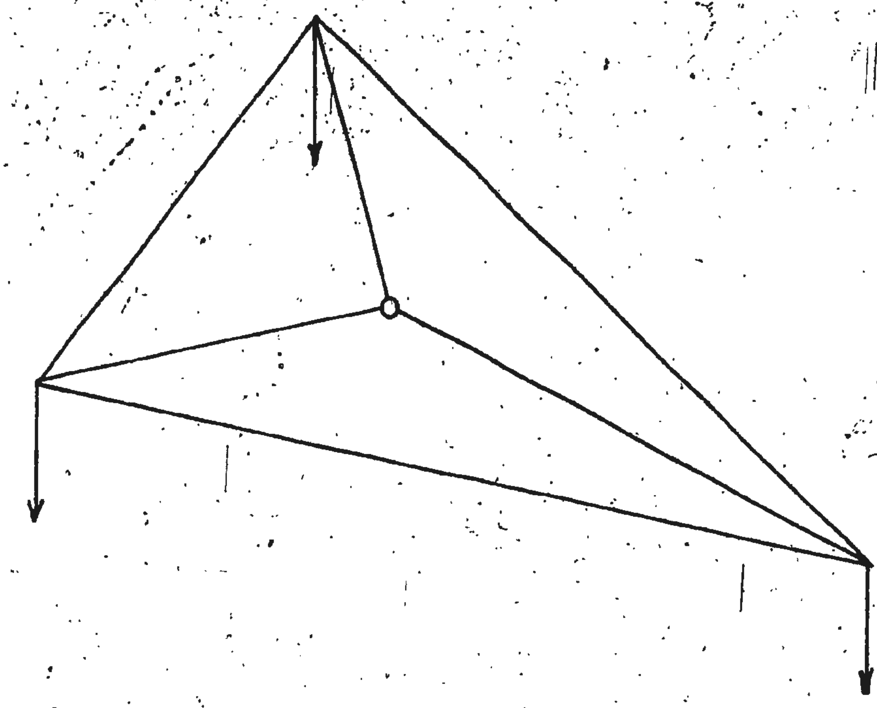

Figure 3 - Locational Polygon for 2 raw materials

Weber presented a mathematical method for determining the ideal location when the locational polygon is a triangle. For more complicated cases, he proposed the use of a mechanical frame[1] which connected each corner to a single centre.

[1] Varigon's frame mechanically locates the resultant of a polygon of forces.

weights proportional to the material indexes acted as forces through pulleys bringing the central knot to rest at the optimal location.

The ideal location found by this method is based only on minimum transport criteria. Next, Weber introduces the modifying influence of wage differentials which act to move the optimal location from the point of least transport costs to a low wage centre. To determine whether it is worth moving to a low wage centre, Weber constructed *isodapanes*, or lines of equal transport cost, around the centre of minimum transport cost. He determined a critical isodapane at which the rise in transport costs, incurred by moving to some point on this line, is exactly equal to the savings in wages. If the low wage centre lies within the critical isodapane, the economies derived from moving to the low wage centre exceed the increased transport costs. Otherwise, it is more economical to remain at the point of least transport costs. Figure 4 on page 19 shows the isodapane effect.

According to Weber, low wage centres either pulled the ideal location all the way to the centre or not at all. In other words, the pull of low labour costs acts only at the low wage centre and a partial move toward the centre will only increase transport costs without decreasing labour costs.

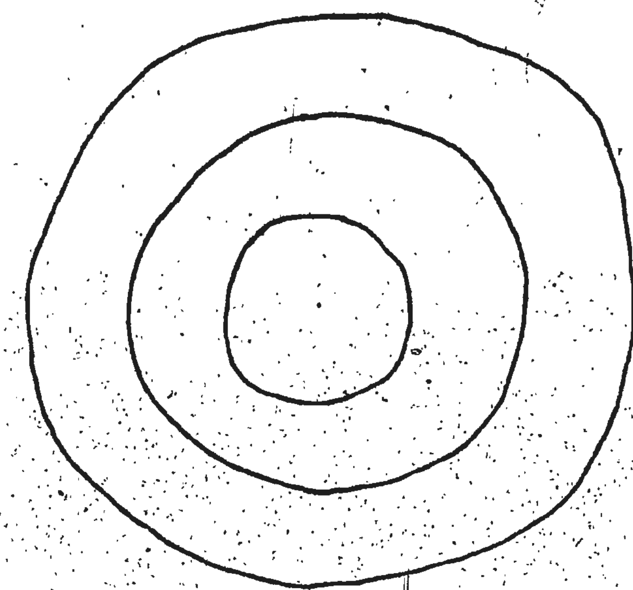

Figure 4 - Isodapanes around a least transport cost centre

After a least transport cost centre has been determined and acted upon by wage differentials, the effect of agglomeration is considered. Agglomeration is a general local factor (transport and labour are general regional factors). It includes forces that tend to concentrate industry such as economies of scale, technical development, skilled labour pools and marketing; it also includes forces that tend to disperse industry such as rent.[1]

[1]Weber excludes all other deglomerative factors such as taxes as being institutional and therefore not part of a pure location theory. He also rules out many agglomerative factors such as insurance, interest and fire and police protection on this basis.

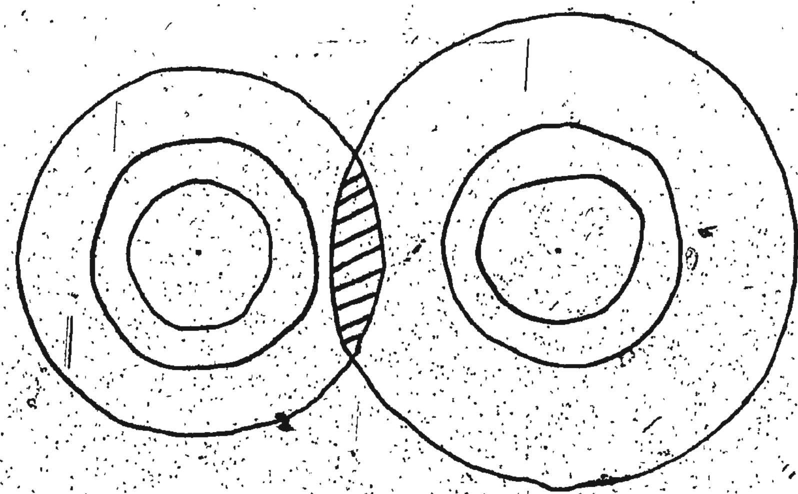

Figure 5 - Intersection of critical isodapanes.

Weber suggests that centres of agglomeration will develop if two conditions are met: "..... the existance of intersections of critical isodapanes ..... and second ..... the attainment of the requisite quantity of production within these segments."[1] The intersection of critical isodapanes is shown in Figure 5 above. It is not clear from Weber's analysis how the quantity of production within the intersected area affects aggolomeration. Also Weber does not indicate how the exact area of agglomeration within the intersection of the critical isodapanes is determined. Agglomeration forces may act on either a point

[1]Weber, Theory of the Location of Industries, p. 136.

of least transport costs or a low wage centre. It is supposed that the entrepreneur will first determine the least transport point and then stepwise consider the attraction of low wage centres and finally the benefits of locating in an area of agglomeration.

Weber's critics have been many as have his disciples. In the following discussion, some of the major criticisms are outlined and related to his assumptions; some of the important outgrowths and applications of his model are summarized.

2.2 Criticism of Weber

From the theoretical point of view, Weber's model had several major shortcomings. Perhaps the most serious of these is the failure to account for locational interdependence between plants. Weber assumed that perfect competition economics applied to location problems. This can be concluded from his assumption that a firm will seek the least cost location to produce a given quantity at a fixed price. However, it is obvious that a firm which minimizes costs, by virtue of its location, enjoys a monopolistic advantage. In other words, if firms locate to minimize costs, the assumption of perfect competition must be abandoned. Such firms would have monopoly advantages within the local area. The practical implication of this is that location decisions must be made with consideration given to the location of existing and future firms. In this way interdependence of plants is acknowledged and accounted for. This aspect of location theory is discussed thoroughly by Greenhut.[1]

A second criticism of Weber is that he excluded many factors as being institutional or special and therefore not part of a *pure* location theory based on general factors only. This can be attributed to his desire to make his theory independent of the prevailing economic and political system and therefore applicable, as a pure theory, to any country regardless of the regime. On these grounds important factors such as cost of capital, insurance, taxes, climate and personal preference were dismissed.

Other criticisms of Weber include:

1) His lumping of power and raw material differences into the transport cost. While such assumptions make for ease in formulation they oversimplify the situation and deviate from reality.

2) His assumption that labour is immobile and unlimited. In reality labour is limited and to some extent mobile. This is borne out by labour migration in search of work.

3) The idea of agglomeration implies that firms will co-operate to work out a mutually beneficial strategy. This is incompatible with the assumption that firms locate one at a time.

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[1]Greenhut, Plant Location, 1956, Chapter 11 and VI.

4) The isodapane solution for dealing with low labour centres leads to indeterminate results. Multiple solutions are possible. Also it is not shown that only one critical isodapane exists. Reality suggests that there would be more than one because labour differences are not homogeneous or regular over space.

5) Transport costs are not uniform over space. Thus Material Indexes pulling the least transport cost centre towards them would have to change as the centre changes location. This point is usually ignored but in reality transportation rates are not linear especially when alternative systems such as rail, ocean and truck or a combination of these are considered.

In spite of these fundamental shortcomings, location theorists have refused to throw out Weber's theory completely. Rather the approach has been to modify the assumptions and make the analysis more formal. An exception to this is the work of August Losch[1] to be discussed later.

The aspect of Weber's theory which has drawn most attention is the idea of locating an industry to minimize transport costs. Although it has been argued that minimum transport criteria are inadequate for locating an industry,[2,3] the problem can be formulated and solved using linear

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[1]August Lösch, Die raumbihe Ordnung der Wirtschaft, 1944.

[2]L.N. Moses, "Location and the Theory of Production," Quarterly Journal of Economics, No. 72, 1958, pp. 259-72.

[3]William Alonso, "A Reformulation of Classical Location Theory and its Relation to Rent Theory," Papers, Regional Science Association, No. 19, 1967, pp. 23-44.

programming techniques. These techniques were not available to Weber, but have been applied extensively to the problem he proposed.[1,2]

2.3 Linear Programming Formulation of Weber's Problem

The simple problem may be stated as follows: Assume that a production process utilizes n raw materials which are available at various sites i (i = 1,n). The process requires an ideal weight[3] W_i of each raw material. The consuming centre demands W_c product. The problem is to choose a production site P, with Euclidian coordinates X_p and Y_p, so as to minimize total transport costs. The number of production sites available is greater than or equal to the number of raw materials locations and the consuming centre combined. All distances are positive.

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[1] Leon Cooper, "Solutions of Generalized Locational Equilibrium Problems," Journal of Regional Science, Vol. 7, No. 1, 1967, pp. 1-18.

[2] H.W. Kuhn and R.E. Kuenne, "An Efficient Algorithm for the Numerical Solution of the Generalized Weber Problem," Journal of Regional Science, Vol. 4, No. 2, 1962, pp. 21-33.

[3] The concept of ideal weight was used by Weber to accommodate real freight rate structures based on bulk, full carload, half carload, etc.

In mathematical notation this becomes, Minimize

$$Z = \sum_{i=1}^{n} \{W_i [(x_i - x_p)^2 + (y_i - y_p)^2]^{1/2}\} + W_c [(x_c - x_p)^2 + (y_c - y_p)^2]^{1/2} \text{ ----- Equation 2}$$

where Z is the objective function, W_i is the ideal weight of raw material from site i, x_i and y_i are the Euclidian coordinates of site i, x_p & y_p are the Euclidian coordinates of the optimal production site P, W_c, x_c and y_c are the weights and coordinates associated with the consumption site C.

To simplify notation, the consumption site can be treated as another raw material site as long as it is identified. Also $[(x_i - x_p)^2 + y_i - y_p)^2]^{1/2}$ can be replaced by d_{ip} (the distance from site i to the optimal production site). The objective function is now

$$\text{Minimize } Z = \sum_{i=1}^{n} W_i \, d_{ip}$$

The necessary and sufficient conditions for x_p and y_p to be a solution to Equation 2 are found by setting the partial derivatives of the function Z to zero.

$$\frac{\partial Z}{\partial x_p} = \sum_{i=1}^{n} W_i \frac{(X_i - x_p)}{d_{ip}} = \sum_{i=1}^{n} \frac{W_i (x_i - x_p)}{[(x_i - x_p)^2 + (y_i - y_p)^2]^{1/2}} = 0$$

$$\frac{\partial Z}{\partial y_p} = \sum_{i=1}^{n} W_i \frac{(Y_i - Y_p)}{d_{ip}} = \sum_{i=1}^{n} \frac{(y_i - y_p)}{[(y_i - y_p)^2 + (y_i - y_p)^2]^{1/2}} = 0 \quad \text{--- Equation 3}$$

These conditions may be interpreted as requiring that point (x_p, y_p) belongs to a convex set, and in general, that all points of the distance function belong to the same convex set. In a two dimensional space this implies that any straight line between two of the points should have all of its points in the same set.

Equation 3 has no exact mathematical solution and must be solved by numerical methods for the variables x_p, y_p. An effective numerical method starts with an approximation of the solution and adds or subtracts the amount from which the approximate solution differs from zero divided by the rate of increase or decrease of the function at the approximate solution point. In other words, if we have an estimate of U_t for which f(U) is zero, the next estimate, $U_{t+1}=U_t - f(U_t)/f'(U_t)$. This is the principle used in the linear programming solution to the Weber problem as proposed by Kuhn and Kuenne[1] and Cooper.[2]

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[1]Kuhn and Kuenne "An Efficient Algorithm for the Numerical Solution of the Generalized Weber Problem," 1962.

[2]Leon Cooper, "Solutions of Generalized Locational Equilibrium Models," 1967.

$$x_p = \frac{\sum_{i=1}^{n} \frac{w_i x_i}{d_{ip}}}{\sum_{i=1}^{n} \frac{w_i}{d_{ip}}}$$

------ Equation 4

$$y_p = \frac{\sum_{i=1}^{n} \frac{w_i y_i}{d_{ip}}}{\sum_{i=1}^{n} \frac{w_i}{d_{ip}}}$$

These values for x_p and y_p are used to determine the value for $d_{ip} = [(x_i - x_p)^2 + (y_i - y_p)^2]^{1/2}$. When the differences between successive values of d_{ip} are small the optimal solution has been found. The weighted average or centroid is a good starting point and the optimal solution is usually found in less than ten iterations. Cooper has considered the more general case where more then one consumption centre is allowed, where supply limitations are imposed and where goods may move in either direction.[1,2] The case of non-linear transport costs is also considered by Cooper.[3]

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[1]Leon Cooper, Heuristic Methods for Location - Allocation Problems," SIAM Review, 6, 1964, pp. 37-52.

[2]------, "Location - Allocation Problem," Operations Research, 11, 1963, pp. 331-343.

[3]------, "An Extension of the Generalized Weber Problem," Journal of Regional Science, Vol. 8, 1969, pp. 181-97.

These developments arose out of Weber's location theory and are valid applications where least transport costs are the only criteria for choosing a location. They also suffer from the least cost-profit maximization problems discussed above. An important conclusion from Weber's work is that the level of transport costs has no influence on the spatial patterns of industry because it affects all industries alike.[1] This somewhat paradoxical conclusion is adequately explained by Weber in terms of weight losing processes and the function of ubiquities.[2] Hence, Weber uses materials indexes and not simple materials weights.

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[1]Weber, Impact of Uncertainty on Location, 1972, pp. 32-3.

[2]Weber defines ubiquities as materials that are available everywhere with no locational cost differences. Such goods tend to pull the ideal location towards the market.

Chapter 3

Hotelling - Interdependence Models

A type of location model based on the interdependence of plants was introduced by Hotelling in 1929[1] and significantly modified by Smithies in 1941.[2] Hotelling made the following assumptions:

1) buyers are uniformly distributed along a linear market of given length and have identical tastes.

2) buyers have an inelastic demand for the good but must pay transport costs (linearly related to distance).

3) sellers can change location at zero cost.

With these assumptions, Hotelling predicted that two sellers will make spatial adjustments until they are located back to back at the centre of the market. This can be argued deductively as below but can also be shown mathematically.[3]

Suppose that the first firm A locates somewhere on the bounded linear market. Firm A will still command the

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[1] Harold Hotelling, "Stability in Competition," Economic Journal, Vol. 39, 1929, pp. 41-57.

[2] Arthur F. Smithies, "Optimum Location in Spatial Competition," Journal of Political Economy, Vol. 49, 1941, pp. 423-39.

[3] Webber, Impact of Uncertainty on Location, 1972, pp. 32-3.

entire market because the consumers' demands are inelastic. When the second firm B wishes to locate, the best choice is immediately next to A but in the longer segment of the market. However, it is now profitable for A to jump over B and locate immediately next to B and serve the longer market segment. This process will continue until after n adjustments, both firms are located contiguously at the centre of the market. At this point, further moves cannot increase either firm's share of the market. The sequence is illustrated in Figure 6 below.

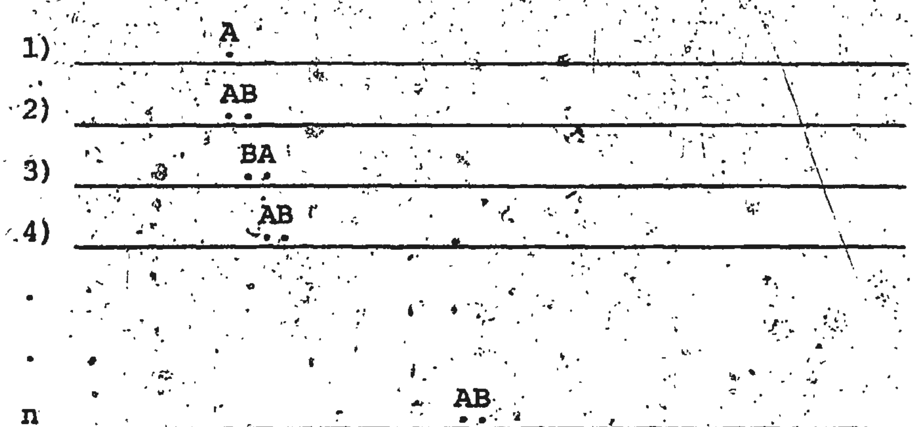

Figure 6 - Spatial adjustment in a linear market

Hotelling claimed that a third firm C would also locate next to A or B but not between them at the centre of the market; he did not pursue the idea but this claim was refuted by Chamberlin[1] and Lerner and Singer.[2] These

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[1] E.H. Chamberlin, Theory of Monopolistic Competition, eighth edition, 1933.

[2] A.P. Lerner and H.W. Singer, "Some Notes on Duoply and Spatial Competition," Journal of Political Economy, Vol. 45, 1937, pp. 145-86.

authors pointed out that the middle firm would lose its market and therefore jump over one of its rivals to get on the outside. Equilibrium will be reached with two firms at one quartile and a single firm at the other quartile. See Figure 7.

Figure 7 - Three firms in a linear bounded market.

If, in this situation, the single firm B tries to increase its market by moving to the centre, it will be in C's interest to jump over B to get a larger share of the market. Lerner and Singer further argued that a fourth firm would join the single firm at the quartile, and that in general firms would locate in pairs. If an odd number of firms shared the market, the single firm could not be at the end because, in this case, it would pay the single firm to locate next to the nearest pair.[1] Where three firms are competing, the firm in the centre can move to any location between the other two (located at the quartiles) and will still enjoy the same share of the market - one quarter. In this case, sales are exchanged by the outside firms. A's loss is B's gain and vice versa. However, as soon as either A or B moves towards the centre, C will jump to the outside.

[1] Ibid

Smithies'[1] work substantially improved the interdependence model. He removed the assumption that buyers' demands are inelastic which implies that buyers have infinite incomes and replaced it with the realistic assumption that demands are price elastic. In other words, as the delivered price increases (based on increasing transport costs in this case) demand will fall off. Smithies also made clear another assumption implicit in the interdependence model - that each firm expects no counteraction from its rival.

With these changes, Smithies envisaged four possible situations as follows:

1) The market is controlled by a monopolist who locates in the centre to maximize sales.

2) The market is shared by two firms who react equally. If one invades the other's territory, it loses sales in its own region; but the other firm is expected to react equally. Therefore they will locate at the quartiles.

3) The market is shared by two firms who expect each other to adjust price equally but not react locationally. In this case, each firm will move toward the centre hoping to gain at the expense of the other. They will locate closer to the centre than the quartiles.

4) The market is shared by two firms who do not expect price or location adjustments by each other. In this case, they will locate near the centre and share the market equally.

Smithies' conclusions rest on the assumption that the

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[1] Smithies, "Optimal Location in Spatial Competition." JPE, 1941.

precise relationship between the cost of transport and the price elasticity of demand is known. Otherwise it is not possible to envisage a stable solution and the model is indeterminate.

It has also been argued that demand is not uniformly distributed in space but is discontinuous.[1] Once this argument is admitted, the validity of the interdependance model is seriously challenged. In spite of this fundamental weakness in the model, several researchers have used it to analyse locational competitivity between firms. Neutze, in 1967, postulated a circular market, rising incomes and locations that are fixed once chosen.[2] Hay, in 1976, assumed that firms locate in sequence and once located are fixed because of the great capital cost of moving.[3] Economies of scale are allowed in production, demand schedules are identical and linear and the market is linear. Hay develops the model very convincingly but in his conclusions maintains that his model is "more useful as an actual location model than the usual analyses of spatial

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[1] G. Ackley, "Spatial Competition in a Discontinuous Market," Quarterly Journal of Economics, Vol. 16, 1942, pp. 212-30.

[2] G.M. Neutze, "Major Determinants of Location Patterns," Land Economics, Vol. 43, 1967, pp. 227-32.

[3] D.A. Hay, "Sequential Entry and Entry - Deterring Strategies in Spatial Competition," Oxford Economic Papers, Vol. 28, 1976, pp. 240-57.

competition."[1] While this may be true in a comparative sense, the model has no real value as an actual location tool because of the extremely limited scope of application. For example, while linear markets may be justified, other totally independent factors such as labour, raw materials, power and taxes are not considered.

In summary, models based on interdependence have little application in location theory and even less in actual location decisions. They predict socially non-optimal results which are at odds with reality e.g. location at the centre rather than at the quartiles. Another fundamental drawback is that these models are essentially retail oriented and when applied to production situations quickly lose all semblance to reality. These models are clearly game theory applications and it is likely that reformulation into a rigorous game theory framework would be revealing.

[1] Ibid, p. 252.

Chapter 4

Losch - Market Oriented Model

The last writer to provide a separate strand of thought in location theory was Agust Lösch in 1939 with his Central Place Theory.[1] An English translation of Lösch was not widely available until after the Second World War.[2] This work had a major influence on location theory in particular and on regional science in general.

Weber and von Thünen considered the market to be a point having no dimensions, only co-ordinates. Hotelling postulated a linear market. Lösch conceived the market as an area, the size and shape of which exerts a determinate effect on the patterns of town growth and industrial location.

Lösch imposed five conditions which, if satisfied, would ensure meaning and permanance to the economy of a region but not necessarily harmony. In Lösch's words, "The best location for producers is not necessarily also the best for consumers."[3] Hence the broad differences

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[1]Lösch, Die Raumliche Ordnung der Wirtschaft, 1939.

[2]Lösch, The Economics of Location, trans. by W.H. Woglom (1952) from the second revised edition of 1943. Henceforth referred to as Losch's "The Economics of Location."

[3]Ibid, p. 98.

between agricultural land use models (von Thünen) and industrial location models (Weber). Lösch's five conditions accept and imply this distinction whereas most location theorists have attempted to integrate the models.[1,2] They are:

1) *The location for an individual must be as advantageous as possible.*

2) *The locations must be so numerous that the entire space is occupied.*

3) ... in all activities that are open to everyone *abnormal profits must disappear.*

4) ... *the areas of supply, production and sales must be as small as possible.*

5) *At the boundaries of economic areas it must be a matter of indifference to which of two neighbouring locations they belong.*[3]

Webber's succinct summary of the meaning of Lösch's conditions is worth repeating. "The first circumstance is that firms maximize income; the last is that consumers maximize income; and the second, third and fourth imply that society maximizes the number of firms."[4]

Lösch then assumed that existence of an unbounded homogeneous plain with resources evenly and adequately

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[1]Water Isard, Location and Space Economy, 1956.

[2]Greenhut, Plant Location, 1956.

[3]Lösch, The Economics of Location, Chap. 8.

[4]Webber, Impact of Uncertainity on Location, pp. 23-4.

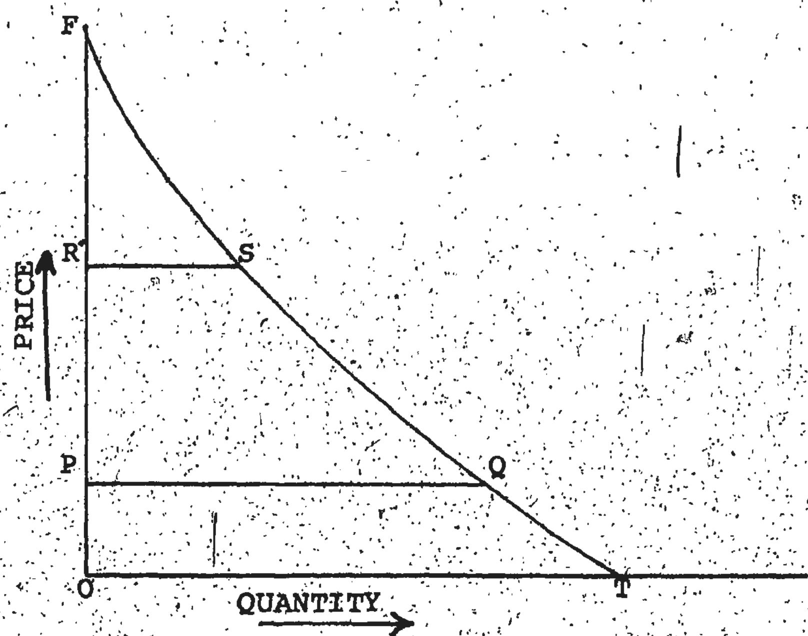

Figure 8 - Demand Curve as a function of distance.

distributed over the plain and populated by self-sufficient farms of regular distribution. The plain is further characterized by uniform transport costs and all consumers have the same demands. With these assumptions Lösch explores what happens when one of the farmers wishes to manufacture a good beyond his own needs and market the excess to his neighbours who must pay for the transport of the good from the producer to where they live. The demand curve for the good is shown in Figure 8 above. O P is the price at the production site and P Q is the volume sold at this location. Consumers who live at some distance from the production site will buy less of the manufactured good as distance increases. At point F, increased transport costs become prohibitive and the quantity bought is zero.

Rotating the triangle PQF about the axis P Q produces a cone. The volume of the cone multiplied by population

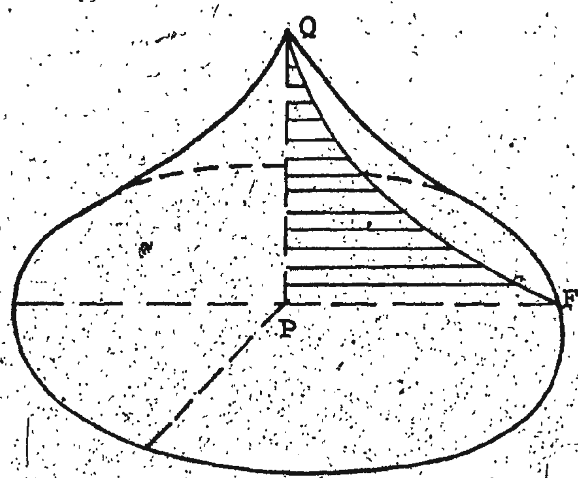

Figure 9 - Demand Cone; found by rotating triangle PQF about axis P Q.

density represents total demand. This is shown in Figure 9 above. Unless the price OP at the production centre is known, the axis of rotation is not known and therefore the total demand or market cannot be determined. Therefore, total demand must be computed for different prices to obtain the demand as a function of price. In effect, this means that the distance OP in Figure 8 on page 37 is different for each selling price. The lower the price the more will be sold and vice versa. Since customers are paying for transportation, the total volume sold will decrease as distance from the production site increases. For each different unit price a different volume will be sold until at point F demand drops off to zero. If total demand or quantity sold is plotted against the different unit prices the market cost curves can be obtained.

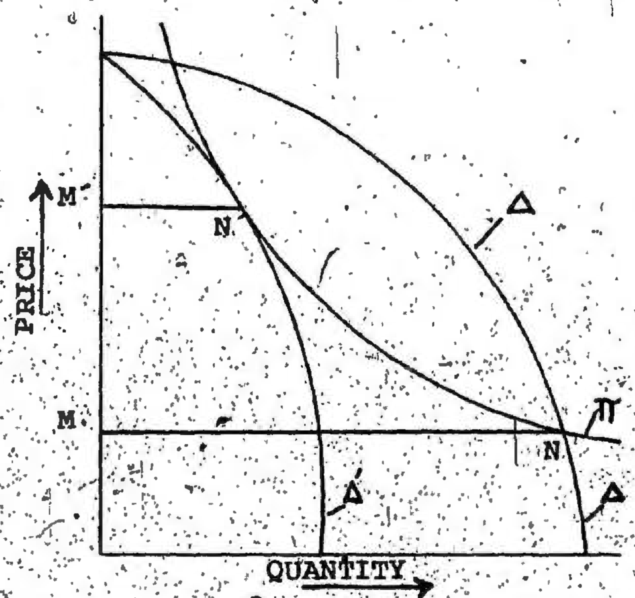

Figure 10 - Cost Curve displacement in a filled market.

This results in the curve Δ (convex to the orgin) shown in Figure 10 above. The curve π (concave to the origin) represents the minimum average cost of production in a given plant. Only if these curves intersect, can profitable production take place. Under the most favourable conditions a quantity MN will be sold.

This situation represents only one farmer in production serving a circular market area. But Lösch's conditions two, three and four rule out abnormal profits which means that the market will be open for other enterprising farmers. Also, condition two requires that everyone must be served. This means the circular market area must be abandoned because of the unserved interstices between adjoining circular markets. Instead, a shape that will cover the entire market must be found. Lösch argues that the hexagon is the ideal shape because it is most like a circle and it can fill the entire space. The only other two shapes which can fill the entire space are squares and equilateral triangles. But the total volume (demand) remaining in a given cone after being pared down parallel to the axis so that the base is an equilateral triangle, a square or a hexagon of equal area will be maximized by the hexagonal shape. Lösch calculates that the total demand in a hexagon is 2.4% greater than in a square and 12% greater than in an equilateral triangle.[1] The hexagon also contains greater demand than a circle (by 10%) if the empty corners are included. Thus Lösch reasons that the market area will fill up and abnormal profits will disappear. The curve of demand as a function of price will be displaced towards the origin. In figure 10 this is represented by Δ'. Now the producer can sell only $M'N'$ and the firm is at its minimum profitable size satisfying conditions three and four. If Δ' does not touch π in Figure 10, the producer will go out of business; if it intersects, there is room in the market for more producers. In this manner, a network of hexagonal market areas develops.

Lösch's extension of the model from one good to a group of goods is not as convincing as the initial phase. First he allows for discontinuity of population and hence demand. Effectively this means that population con-

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[1]Ibid, p. 113.

centrations in the form of hamlets and villages dot the landscape. The distance between production centres will be equal to the distance between the settlements supplied, multiplied by the square root of their number.[1] Lösch argues this point on a geometric basis with the assumption that production sites will be located on farms or equidistant between three farms. In order to extend the system for many goods, Lösch proposed that all market areas have at least one centre in common. This means that everyone should have at least one market for a particular good. He therefore rotated the hexagonal nets about the common centre producing twelve sectors. Six of these would have many production sites and six would have few production sites. This is explained as agglomeration effects.

> With this arrangement the greatest number of locations coincide, the maximum number of purchases can be made locally, the sum of the minimum distances between industrial locations is least, and in consequence not only shipments but also transport lines are reduced to a minimum.[2]

The resulting self-sufficient region or group of regions Lösch calls the ideal economic landscape. Such regions are distributed throughout the world like a network and in accordance with definite laws.[3]

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[1]Ibid, p. 118.

[2]Ibid, p. 124.

[3]Ibid, p. 137.

A hexagonal network where every town dominates three towns of the next lowest rank is shown in Figure 11.[1] Two significant extensions of Losch's Central Place Theory

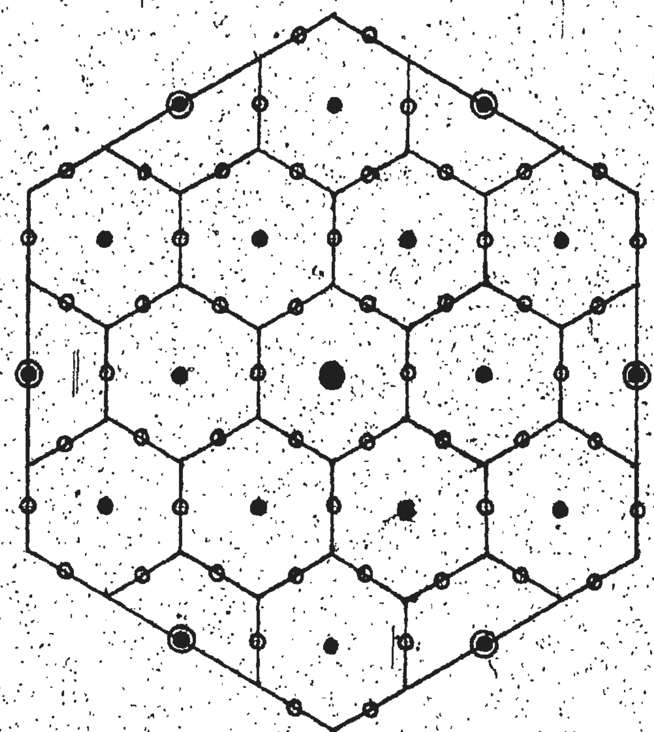

Figure 11 - Hexagonal network of towns. Each town dominates three towns of the next lowest rank.

have developed. Christaller in 1966 made formal the agglomeration argument in Losch's theory by assuring that a central place provides a function of order M if and only if it also provides functions of all orders less than M.[2]

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[1]Lösch, The Economics of Location, 2nd. ed., 1953, p. 132.

[2]Summarized from Webber, Impact of Uncertainity on Location, pp. 26-7.

Leamer in 1968, extended Central Place Theory to a bounded market and showed that when the number of firms exceeds 10, the market areas will be hexagonal except at the boundary.

Lösch's work has been greeted as a breakthrough in location theory because it related the cost of production and the market area. The major shortcomings of the theory arise from the assumption of an homogeneous landscape e.g. an even distribution of resources. In practice, this condition is far from true with the result that the regular geometric pattern is highly distorted. Another problem is the mechanism whereby agglomeration factors generate central places. In order for this to occur, locating firms must co-operate by locating simultaneously or adjusting their locations to exploit agglomerative advantages.

The real value of Lösch's theory is that it has focused attention on the importance of the market and how its size and shape influence the pattern or industries and towns. As such it can provide insight into the size and distribution of cities. In this respect, Lösch's Central Place Theory has been, at least to some extent, empirically proven.[1]

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[1]Ibid, p. 29.

Chapter 5
Other Major Trends in Location Theory

Two other significant trends in location theory require some discussion. These are the empirical studies and the use of mathematical programming techniques to minimize transport costs. While these are not part of location theory, in a pure sense, they are important because they confirm or refute pure theory and show how the predictions of pure theory deviate from reality.

5.1 Empirical Studies

There are several broad headings under which empirical studies relating to location decisions may be grouped. These include 1) location decisions seen as part of an investment strategy 2), pure location decisions and 3) location adjustment decisions.[1] Only the second group will be discussed here. These studies are extremely common in location literature and all of them adopt the same basic approach. A researcher wishes to find out any or all of the following:

1) Why a specific industry is moving to or from a specific region.

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[1]Gunter Krumme, "Toward a Geography of Enterprise," Economic Geography, Vol. 45, No. 1, 1969, pp. 30-40.

2) Why industry in general is moving to or from a specific region.

3) Why industry in general is moving.

4) Which factors e.g. labour costs, transport costs, etc. are considered important in reaching a locational decision.

With these objectives, the researcher then formulates a questionaire or interview format or uses both questionaire and interview combined to seek answers to specific research questions. The best empirical studies employ both techniques and work from carefully formulated hypotheses which are based on indepth studies of several cases. These hypotheses are then systematically tested using cases especially chosen for the purpose.[1] Some extensive and comprehensive empirical studies have been made that shed light on locational decision making.[2,3]

The results of most empirical studies are usually published in the form of guidelines with a discussion of the techniques employed. It is intended that these guidelines be employed by firms contemplating a location decision. As such they are generally inadequate. The

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[1] Söderman, Industrial Location Planning, 1975.

[2] W.F. Luttrell, Factory Location and Industrial Movement: A study of Recent Experience in Great Britain, Vols. 1 and 2, 1962.

[3] R.M. Cyert and J.G. March, A Behavioural Theory of the Firm, 1963.

merits of empirical studies such as those footnoted are that they provide insight into the decision making process of the firm and help determine to what extent theory deviates from reality. As decision tools, the most they can accomplish is a relative listing of factors which other firms considered important. Many comprehensive sets of guidelines are available.[1]

Two obvious drawbacks of empirical methods as they have been applied to location decisions are as follows:

1) Such studies must take place after the decision has been made and executed. This fact removes the researcher in time and space from the actual decision process; hence first hand observation is impossible.

2) The accuracy of the response to the research questions is subject to how well the details of the decisions remain in the mind of the person completing the questionaire or being interviewed. Also, how representative that person's opinion is of the actual decision facts affects the accuracy of the results. In practice, the researcher must assume that the respondent's opinion is identical with that of the firm or reject it entirely.

These problems are part of the method and, although they may be counteracted by a good researcher, they can never be eliminated. Many other problems arise which appear

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[1]See Appendix 1 for an example of such sets of guidelines.

in some empirical studies but are avoided in others. These include:

1) identification of the factors to be ranked is done by the researcher, not the respondent.

2) questions are too general for meaningful interpretation.

3) the terms site, region, area and community are often confused.

4) ranking of factors reduces the complex decision process to overly simplistic terms.

5) analysis is superficial and lacks internal probing necessary to link the location decision with other aspects of the firm.

6) the interaction of persons involved in the location decision is ignored; it is assumed that only one person made the decision.

7) qualitative factors are ignored or are acknowledged but not analysed sufficiently because of the problems of quantification.

One unfortunate outcome of empirical studies is that regional governments may decide, on the basis of them, that one or more particular factors are crucial for development. Costly projects to provide the attracting service factor such as water and sewage or transport links are mounted and justified by citing the study which named these as being most important. It then becomes obvious, after great amounts of money have been spent and possible environmental damage has been incurred, that such factors taken in isolation, mean very little to an entrepreneur choosing a location for his enterprise. Indeed these projects often have the opposite effect because of the high level of future taxes they impose on a locating industry.

In this regard, regional governments should look closely at the experience of others and endeavour to find out what real or natural attracting factors their regions possess. Improved service factors can enhance natural advantages but can never replace them. Attracting an industry for the wrong reasons will inevitably lead to failure or high subsidization; neither of these is acceptable when compared to industries which flourish because they have taken advantage of natural regional factors.

Perhaps the most important contribution of empirical studies to location theory is that they show the wide variety of factors considered as important in making a location decision. This is in sharp distinction to models built on one overriding factor such as transport, market, labour or agglomeration. Krumme has prepared a list of empirical studies and a related list of most significant factors and reasons mentioned as being most important. Krumme's list is reproduced in Appendix 2.[1] These factors include personal reasons, expansion, trucking, taxes, land costs, restrictive zoning, materials and labour to name just a few.

This singular phenomenon is sufficient to challenge

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[1]Krumme, "Toward a Geography of Enterprise," Exonomic Geography, p. 35.

the spatially optimal industrial landscape predicted by location theories. Indeed, few entrepreneurs would trust their fortunes to such predictions and few theorists would ask them to. It seems clear that the predictions of a model built on the consideration of one major factor, with unrealistic assumptions about the distribution of resources and demands, will be at variance with real decisions which endeavour to take all factors into account when an actual location is chosen. Lösch's response to the divergence between theory and reality is most satisfactory. He claims that reality does not provide a check for theory but rather that theory can be used to check reality. Lösch fully anticipates that great differences will be evident but maintains that: "What pure theory describes, holds only under its simple assumptions. For this reason it is so difficult to explain by pure theory what has historically developed."[1]

5.2 Mathematical Programming

Mathematical programming brings to location theory a ready made set of algorithms for solving location - allocation problems and a rigorous framework for their application. Linear programming is the best developed of these techniques and has proved irresistable to researchers

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[1] Lösch, The Economics of Location, 2nd, ed., 1953, p. 358.

looking for a powerful mathematical tool to tackle the location problem. One such application of linear programming to the Weber problem as initially proposed (i.e. choose a production site so as to minimize total transport costs) was developed on pages 24-27. This is a valid approach to choosing a location as long as 1) transport costs are so large that other costs which vary locationally can be ignored 2) the transport cost function is linear and 3) plant locations are independent. In reality none of these three conditions applies. Still, an attempt has been made to justify the application of linear programming techniques by formulating the objective function so that only transport costs are considered and by assuming that the transport cost functions are approximately linear. Interdependence of plants is not considered.

Mathematical programming models which attempt to locate optimal production points on a network of predetermined and fixed points have also been developed. Some of these are capable of taking the fixed costs associated with establishing a plant into account. The idea is to reach a minimum cost solution by balancing the costs of distribution against the cost of facilities. This is the well known location - allocation problem to optimally allocate sources to demands with the additional problem of optimizing facility costs within the model. It is assumed that demands are known and that the possible site locations are known. The mathematical formulation is as follows.[1]

Minimize the objective function Z,

$$Z = \sum_{j=i}^{n} \sum_{i=1}^{m} d_{ij} (x_{ij}) + \sum_{i=1}^{m} F_i (Y_i) \text{ ----- Equation 5}$$

subject to the following constraints.

$$\sum_{j=1}^{n} x_{ij} = Y_i \quad , \quad i = 1,m$$

$$\sum_{i=1}^{m} x_{ij} = d_j \quad , \quad j = 1,n$$

$$x_{ij} \geqslant 0 \quad , \quad i = 1,m; \; j = 1,n$$

$$Y_i \geqslant 0 \quad , \quad i = 1,m$$

where

x_{ij} = Amount shipped from plant i to demand j

Y_i = Total Amount shipped from plant i

d_{ij} (x_{ij}) = Cost of shipping x_{ij} from i to j

F_i (Y_i) = Facility cost associated with Y_i

$F_i(Y_i)$ is usually nonlinear and represents large fixed costs for land, buildings, utilities, etc., before any product can be produced or stored. However, once production is started, the cost per unit will likely decrease because of economies of scale. Thus $F_i(Y_i)$ does not meet the requirement of linearity necessary for

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[1] This formulation is based largely on "Mathematical Models of Location: A Review" by O.H. Marks et al, Journal of the Urban Planning and Development Division, Proc., ASCE, March, 1970.

a straight forward application of the technique. In fact $F_i(Y_i)$ is a concave function and does not meet the conditions set down on pages 25 - 26. The concave function $F_i(Y_i)$ for the fixed cost of facilities is the problem to which most researchers have given their attention.

Several efficient methods have been developed utilizing the branch and bound technique.[1,2] In this method the non-integer result at each iteration is an obvious solution to a simple linear programming problem.[3]

This problem is, in a general way, similar to the plant location problem. However, the warehouse problem is often referred to in the literature as a plant location problem. This is unfortunate because it leads to confusion. For example, one feature of the multiplant problem is that each plant must be capable of meeting all of the demands if it is called upon to do so. Very few writers take the trouble to point out this often unrealistic requirement;[4] it can usually be identified by the word 'simple' in the problem title or

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[1]M. Efroymson and T. Ray, "A Branch and bound Algorithm for Plant Location", Operations Research, Vol. 14, 1966, pp. 361-8.

[2]Kurt Spielberg, "Algorithms for the Simple Plant Location Problem with some Side Conditions", Operations Research, Vol. 17, 1969, pp. 85-111.

[3]Branch and bound is a technique used to solve integer-programming problems where non-integer solutions are not feasible and hence the problem is nonlinear.

[4]An exception is Kurt Spielberg, "Algorithms for the Simple Plant Location Problem with some Side Conditions", Operations Research, Vol. 17, 1969, p. 85

description. It is not inconceivable that each new plant be capable of meeting all of the demands but it should be pointed out that this requirement is usually adopted to simplify the mathematics.

These problems would have an application, for example, in 1) designing a solid waste collection system including facilities location for a large metropolitan area and 2) the location of a system of warehouses for a new distribution system. Even in these applications, the 'simple' requirement could create problems in the actual solution. In other words, the solution method does not specify a limit to the size of the warehouse or plant but assumes that the size can be increased if the demand for that particular facility increases. In practice, such flexibility is not generally available.

PART II

A METHOD FOR EVALUATING INDUSTRIAL LOCATION ALTERNATIVES

Chapter 6

The Method and Concepts

Part I of this paper dealt with the major seminal contributions to location theory and traced these ideas to their present day applications. In addition, the shortcomings of each major theory were related to the assumptions on which the theory was developed. The work of many important researchers in the field was not explicitly examined but referred to only as it affected the several major and distinct strands of theory that have developed.

As mentioned in the introduction, the method employed in this work is to draw on the various theoretical and empirical studies of the location problem to devise a straightforward and practical tool for choosing an efficient location for a manufacturing or production process.

In location theory literature, little exists in the way of practical methods that can be used by the firm facing a location decision. Perhaps the most useful of these can be found in books that are put out by firms or associates of firms who make a business of locating plants for others.[1] Even so, these cannot be properly called "methods" as they really are only guidelines. In the same vein, sets of guidelines are published[2] which list many of the factors that may affect the choice of location. The user is advised to choose those which apply to his particular industry and to use any convenient point system in reaching a final decision.

Very little exists in the way of rigorous methods are available to the decision maker for distinguishing locations which will lead to maximum profits. It is precisely to this problem that the current work is meant to contribute. It should be stated immediately that the objective of this study is to develop a practical, rigorous and straightforward method for locating plants. Each of these three qualifiers will now be defined.

By practical it is meant that the method should operate in the realm of the balance sheet. A decision maker may admit of considerations that are not usually translated into monetary values but it is felt that such considerations, commonly called intangible can, with a

[1] Leonard C. Yaseen, Plant Location, 1956, American Research Council, Inc., New York.

[2] One such set is contained in Appendix I.

little manipulation, be converted to practical values.[1,2] It may be that some factor, identified as personal and therefore intangible, cannot be converted to dollars. Even so, by including it in the analysis, some idea can be gotten of how much will have to be paid, in terms of lost profit potential, to satisify this requirement.

By rigorous it is meant that the method should operate in a precise manner and should be amenable to checking by others familiar with the industry and the method. This means that intangible factors such as labour climate and community attitude, if they are to be used as location factors, must be converted to quantifiable terms in a meaningful way. Many location decisions are made on a 'hunch' basis without applying any evaluative techniques to the decision process. By using a well defined method, it is felt that these decisions can be put on a factual basis and either justified or shown to be profit limiting. In either case, an analytical technique which reduces the speculative element in location decisions should be welcome.

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[1] This agrees with Greenhut, Plant Location, 1956 where he claims that personal considerations can really be reduced at least partially to economic terms. He offers no method for the conversion.

[2] Hisao Nishioka, "Location Theory in Japan," Progress in Geography, Vol. 7, 1975, pp. 133-200. Nishioka's study points up the importance of personal considerations and suggests that these could also influence other factors, pp. 159-161.

By straight forward it is meant that the method should be clear and logical in its approach with a minimum of clutter from either its formulation or language. In this regard, the method will appeal more to common sense than anything else. If some aspect cannot be firmly grounded in commonsensical reasoning, it must be abandoned.

This does not mean that location decisions will be made simple or that the amount of work required to make such decisions will be reduced. The method proposed will not provide rule of thumb solutions or shortcuts through a difficult problem area. What it will do is break the decision down into easily discernible steps that can be looked at independently and then combined in a way which will identify the best solutions. The plural is used because it is recognized that there can be no one best solution to a problem encompassing so many and varied factors as choosing a production location. How good a solution is developed depends in large part on how good a set of alternatives is available from which to choose. It must be recognized that a method which does not select the best set of alternatives is not an effective method; neither is a method which selects the best of a set of alternatives and does not reveal that all of the alternatives are degenerate. This means that an effective method must not only identify the best relative solutions, but must also indicate whether or not such solutions have inherent merit. In other words, the method must evaluate alternatives in both a relative and an absolute sense.

The three tenets on which the proposed method is to be based are as follows:

1) Factors which influence location choice are of two basic types. They are critical and noncritical. Critical factors must be present in minimum form or the location is not viable at all. Noncritical factors have a direct effect on profit potential but generally will not bring about the failure of the enterprise if overlooked.

2) All factors, whether they be critical or noncritical, must be evaluated in terms of their locational variance and their relative importance or size in the cost structure of the industry in question.

3) A potential location must be evaluated not only in terms of location factors, which are essentially cost related, but also in terms of the demand or market share which can be expected if that location were chosen. This is nothing more than a market forecast with the effect of location taken into account.

Each of these three will now be discussed in detail. It will be recognized that there is really nothing new in either of these three ideas except perhaps the combining of variance and relative size to evaluate location factors. Very few terms will be used in other than their conventional meaning but any terms used in a special way will be defined when they are introduced.

Chapter 7

Critical and Noncritical Factors

The aspect of location problems which causes the most confusion is the lumping together of critical and noncritical factors. A critical factor is one which must be present for a location to be viable. Examples in primary industry include land for agriculture, forests for pulp and paper and ore-bearing deposits for mining; in general, the immobile raw materials on which an industry is based are critical to its success. The presence of such resources does not necessarily mean an industry will be viable. Market and recovery considerations may still rule out the development of immobile resources. Even if it proves feasible to develop a certain resource, the actual location is not fixed totally by the location of the resource. The availability of power, water, suitable building sites, transport and other factors will be important in fixing an actual location.

In secondary industry, the availability of materials also tends to be critical. However, in this case locational choice is wider because the raw materials must be assembled at the chosen production site; hence a greater interplay between inputs to the process is possible. In the steel industry, for example, the relative importance of iron ore, coal or coke and scrap must be balanced. Here again this tradeoff does not completely determine the actual location. Labour and market considerations, land for production sites, ocean ports and rail links will all influence the final choice.

Clearly the unique feature of critical factors is that they tend to determine the region or regions in which production can take place rather than the specific location. As such they may be thought of as basic prerequisites rather than specific location determinants. They act as broad filtering factors indicating which regions can be considered. It is conceivable that such factors may play little or no part in determining the actual specific location. They provide the first screen or filter which determines in which region or regions production may be considered. It is necessary at this point to distinguish clearly between the terms region, area, community and site.

A region is a geographic space defined by discernible natural boundaries and has generally uniform characteristics. Political boundaries may be imposed over but need not coincide with natural boundaries. Major drainage systems are good examples of natural regions. An area is a restricted portion of a region such as a river delta or a plain having specific uniform characteristics. A community is an established grouping of residential units or a clustering of living spaces. Examples include villages, towns and cities. A <u>site</u> is a specific tract of land suitable for the construction of industrial facilities. It is the most specific of locational terms and generally refers to the exact location within an area or community. Sites may be serviced or unserviced. A site may also be determined by natural characteristics as in the case of hydroelectric installations. Site considerations such as levelness of land, drainage and bearing capacity of soil are only considered after the region, the area and, if applicable, the community have been chosen. At each stage the relevant factors must be considered.

Perhaps the most frequent mistake made in choosing a location is to pick the site before evaluating the region, area or community. Hence an attractive well-serviced and low cost site may be chosen without due regard to climate, labour, raw materials or some other important and perhaps critical factor.

The purpose of this discussion is to establish that the first step in locating an industry is to determine the critical factors which are prerequisites for that particular industry. Only after this has been done can prospective regions and areas be identified. It may turn out that several regions are possible and an evaluation of the merits of the critical factors will usually indicate which region is most suitable. If the choice is still not clear, noncritical factors should be considered. The inherent merit in this approach is that the critical factors receive careful first attention and only after it is determined that these are present in adequate quantity and quality will secondary or noncritical factors be considered.

Location theory recognizes the distinction between critical and noncritical factors. Weber distinquished between general and specific factors;[1] Greenhut referred to factors as being basic or secondary.[2] Kasuga, a prominent Japanese location theorist, discussed the interaction of locational conditions and location factors.[3] Empirical studies also refer to this broad division of factors. The McGraw-Hill survey analysed by McMillan recognizes location prerequisites and location determinants.[4]

One may well ask how are critical and noncritical factors to be distinquished. It would be reckless to imply that the distinction is obvious. Many ventures

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[1] Weber, Theory of the Location of Industries, 1929, pp. 20-24.

[2] Greenhut, Plant Location, 1956, pp. 103-105.

[3] S. Kasuga, "Industrial Location and Regional Orginization," Oita University, Economic Review (Oita Daigaku Keizai Ronshu), Vol. 6, 1954, pp. 88-114.

[4] T.E. McMillan, "Why Manufacturers Choose Plant Locations vs. Determinants of Plant Locations," Land Economics, Vol. 41, 1965, pp. 239-46.

have failed because of inadequate regard to natural regional factors which, for primary industries at least, are always critical. It is fair to say that a person experienced in a particular industry should be able to identify which factors are critical and which factors are noncritical. A pulp and paper plant, for example, requires adequate stands of softwood, an efficient delivery system to the mill site, a skilled labour pool, related technology, an adequate water supply, a power supply and a market for its product. If any one of these is missing entirely or is available in inadequate quantity or quality, a pulp and paper plant will not be viable. This is true regardless of what incentives are available to industrialists from governments. It should be recognized, however, that a certain amount of substitution may take place. For example, an abundant and rich forest resource coupled with a cheap delivery system will permit greater expenditures to bring costly power to the site. However, if the cost of power is excessive or the supply is unreliable, the plant should never be built. This situation is not fixed for all time; as more lucrative resources are used up, or as demand, and hence price, increase sufficiently to justify the cost of transmitted power, the resource may be commercial. Similar reasoning can be applied to any industry considering a location. The important point is that critical factors must be satisfactorily evaluated before consideration is given to noncritical factors. Only in this way can the feasibility of a location be established.

Chapter 8

Variance and Relative Size of Factors

Forgetting for a moment the two tier approach which must be used in evaluating locational factors, the question arises as to how locational factors will be evaluated. By this is meant, what precise method will be used to quantify factors so that a location decision can be made? The idea to be used here is to take the point - weighting method implicit in empirical studies and used in location guidelines and tie it directly to the locational variance and relative size of the cost factors for the industry in question. The real problem with most weighting systems is that they suffer from arbitrariness. No exact method is available for determining the weights which should be assigned to the various factors.

This is similar to the industrial engineering problem in job evaluation schemes. Here a non-arbitrary method is needed to assign weights to job evaluation factors such as skill, effort, responsibility and working conditions. Smalley has pointed out that weight can be tied to variance according to this postulate, "When independent relative measures are combined, they automatically weight themselves in accordance with their respective variabilities."[1]

Hicks recognized the merit of Smalley's postulate and suggested that it could be used to tighten up plant location decisions.[2] He did not consider that the relative size of the factor should also be used to correct the weight. Neither did he consider the influence of demand on locational choice.

According to Smalley's postulate, the weight for any one factor can be determined in direct porportion to the ratio of its standard deviation and the sum of the standard deviations for all factors considered. Expressed mathematically:

$$\omega_i = \frac{\sigma_i}{\sum_{i=1}^{n} \sigma_i} \qquad \text{------ Equation 6}$$

Where ω_i is the weight assigned to factor i, i=1,n

σ_i is the standard deviation of the distribution for factor i, over all locations j, j=1,m and is defined as

$$\sigma_i = \left[\frac{1}{m-1} \sum_{j=1}^{m} (f_{ij} - \bar{f}_i) \right]^{\frac{1}{2}}$$

n is the number of factors to be considered

m is the number of locations for factor i, j=1,m

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[1] Harold E. Smalley, "Another look at job Evaluation," Industrial Management, Vol. 4, No. 8, 1962, pp. 17-22.

[2] Philip E. Hicks and Arun K. Kumtha, "One Way to Tighten up Plant Location Decisions," Industrial Engineering, Vol. 3, No. 4, 1971, pp. 19-23.

f_{ij} is the jth element in the distribution of factor i.

$\bar{f}_i$ is the mean of factor i defined as $\bar{f}_i = \frac{\Sigma f_{ij}}{m}, j=1,m$

Of course, variance, the square of the standard deviation, could be used directly but the standard deviation is a more familiar term. Both reflect the dispersion of scores from a central mean. Since we are only interested in relative measures, the standard deviation will be used.

The appeal of this idea for plant location decisions is strong because it means that if a particular factor is not locationally variable it will have zero weight assigned to it; hence, it will not affect the decision process. In contrast, a factor which is highly variable will receive weight in proportion to its variance and will therefore figure prominently in the decision process. For example, if it turns out that the cost of power is basically the same at all prospective locations, then power is effectively dropped from the analysis. If, on the other hand, it turns out that the cost of labour is highly variable, then labour will receive a porportionately high weighting.

The exact weight for a given factor is determined by multiplying the expected equivalent[1] annual cost associated

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[1]The use of 'equivalent' implies that capital expenditures will be amortized and that intangible values will be converted to practical units.

with the factor by the ratio of its standard deviation to the sum of the standard deviations for all factors. This ratio will be referred to as the factor variance ratio and is defined by equation 6 on page 65. The exact weight W_i is defined by equations 7 and 8.

$$W_i = \frac{\sigma_i}{\sum_{i=1}^{n} \sigma_i} \cdot C_{ij} \text{ ------ Equation 7}$$

or

$$W_i = \omega_i \cdot C_i \text{ ------ Equation 8}$$

Where W_i is the exact weight for factor i

ω_i is the factor variance ratio defined by Equation 6

C_{ij} is the expected equivalent annual cost associated with factor i at location j

The total weight for each location $\sum_{i=1}^{n} W_{ij}$ is determined and the location with the lowest total weight ΣW_{ij} is the least cost location. How the method actually works will be illustrated with an example after the theoretical discussion is complete.

It is clear that use of this method will require a determination of the expected annual costs at each prospective location. It is also obvious that any number of factors and locations can be compared in equivalent terms by applying this straightforward approach. Determination of the expected equivalent annual costs is a most important step and will likely involve a great deal of work. However, there is nothing new in making such a determination, except that detailed estimates are usually done only for the selected location. Extending the process to include all prospective feasible locations as determined in the initial analysis will clearly pinpoint those alternatives which merit further consideration. Because location plays such an important role in the success of an industry, it should not prove difficult to convince an entrepreneur to go through this process.

One of the advantages of using this method is that it looks after the problem of highly visible but proportionately small costs automatically. For example, land costs are usually readily discernible in a location analysis but may amount to such a small porportion of total annual costs that they could effectively be ignored. Instead, what usually happens is that land costs are given greater weight than they merit because they are so visible in the decision process. A less obvious cost factor, like marketing, may be given only passing attention or ignored entirely because it doesn't stand out. Marketing costs may be highly locationally variable and at the same time account for a relatively large share of the cost structure. These, taken together, would mean that marketing should receive a high weighting when comparing location alternatives. The method proposed would automatically ensure that all factors whether they be highly visible or obscure would receive the correct weight in pursuing a location decision.

A less obvious advantage of this method is that some insight into the inherent merit of a location may be gained by including in the analysis one or more established locations already in production. By comparing the costs of these operations with the expected costs of the proposed operation at the different locations, some idea of the expected competitiveness and profitability of the new operation at these locations may be obtained. Because of scale economies such a comparision is best done when expected volume is taken into account. In this way, it will become clear how the proposed location compares with existing locations and whether or not a proposed location has advantages relative to the industry generally or is simply the least cost alternative in a set of poor alternatives. If this proves to be the case, then clearly more alternatives must be generated before a location choice is made.

Needless to say, such comparisons require the gathering of cost data on existing operations unless, of course, the location decision to be made involves a branch plant or a relocation. In these cases comparative data will be available from the firm's own financial records. If, however, the proposed operation is entirely new, it is imperative that comparative data be obtained to test whether or not the proposed operation is feasible on an industry wide basis. Unfortunately it is not always easy to obtain meaningful cost data from existing operations but by using published annual reports and gross input figures combined with a knowledge of the industry involved it should be possible to develop realistic data.

Before moving to a consideration of the influence of demand the problem of how to convert intangible factors and personal preferences into practical values must be dealt with. These factors have usually been ignored entirely in location theory but have been proven to be of great importance by empirical studies into location decisions. The method suggested by Hicks and Kumtha should prove successful for dealing with intangible factors.[1] These authors suggest that intangible factors such as labour attitude and community attitude be identified and described in detail at five discrete but arbitrary levels. The amount of annual costs associated with each level is then identified. For example, community attitude can range from hostile to friendly. Each location is assigned to the most appropriate level and thereby an expected equivalent annual cost is determined. These annual cost equivalents can then be treated in the same manner as any other costs.

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[1] Ibid, pp. 21-2.

This method is arbitrary to some extent but may be tied to some measurable indicators such as vandalism, cost of insurance and security and the number of benevolent business societies the community supports. Its success hinges on the ability to assign relative values to different levels of community service and attitude and to identify those levels in particular communities. Labour attitude can be analysed in a similar way and tied to lost man days per year because of strikes, incidence of wildcat strikes, absenteeism and other labour unrest indicators.

Purely personal considerations may prove impossible to quantify unless the decision maker is prepared to name an annual payment for which a preferred location would be given up. If he is prepared to quantify purely personal considerations, the methods of utility theory could be used to put such considerations on a more rigorous basis. It should be pointed out that all intangible and personal factors are noncritical in nature, although it is possible to envisage community or labour hostility leading to the failure of an enterprise. More often though, such factors are contributory to a shutdown brought on primarily by inadequate consideration of more critical factors or unanticipated changes in critical factors.

When such purely personal factors are considered in a location decision analysis, at least some idea can be obtained of what will have to be paid for a particular location in terms of lost profit potential. This, in itself, is an important piece of information. How exactly intangible factors can be dealt with will be illustrated with an example following the discussion on demand.

Chapter 9

Demand and Market Considerations

If a location decision were made strictly on the basis of the criteria developed in chapter 7 and 8 it might safely be claimed that a least cost location had been arrived at. The development of location theory has shown, however, that least cost location models as put forward by Weber[1] do not necessarily lead to maximum profits.[2] This fundamental argument is also recognized by interdependence location models pioneered by Hotelling.[3] The work of Lösch, firmly established the importance of the market in determining the optimal location pattern for an industry.[4]

In reality, a firm will endeavour to select a location of maximum profit potential. It must therefore consider not only the location and costs of raw materials and other cost-related factors but also the interaction of location and

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[1]Weber, Theory of the Location of Industries, 1929.

[2]For an analytical proof of this see L.N. Moses, "Location and the Theory of Production," Quarterly Journal of Economics, Vol. 72, 1959, pp. 259-72.

[3]Hotelling, "Stability in Competition," Economic Journal, Vol. 39, 1929, pp. 44-57.

[4]Lösch, The Economics of Location, 1943.

demand. This interaction occurs in two distinct ways. First of all, the specific location creates a spatial monopoly in the local area; and secondly, the minimum cost of production establishes the minimum price of the product which in turn affects the demand for the product. It follows then that these two influences of location on demand must be taken into account when making a location decision. Interdependence location models concentrate on the spatial monopoly aspect of location and assume that firms are freely mobile along a linear market. In reality, firms must take a long look ahead when choosing a location because most plants will be depreciated over a fifteen to twenty year life span. In addition, the cost of moving a plant is generally excessive and will not be done until alternatives are exhausted. It is therefore necessary to postulate the permanence of a located facility for a minimum of fifteen years. This minimum period is seen as the location decision planning horizon. A locating firm should therefore seek to delimit its market from encroaching rivals, and to maximize demand through the influence of a competitive price in the market over the minimum location planning horizon of fifteen years. For purposes of this discussion the long, medium and short terms will be taken as fifteen, ten and five years respectively.

It is impossible to know with certainty the action which rivals will take but it is safe to assume that, in the long run, the entire market will be served. This is brought about by new firms entering to supply areas too remote to be economically supplied by the nearest existing firm. Therefore, in the long run, the firm's market share will be reduced to the area of its spatial monopoly unless spatial adjustments are made. With such uncertainty and market dynamics, how does a firm go about choosing a profit maximizing location?

Clearly the firm must specify its objectives in the short, medium and long run and some decisions must be made as to expected production volume. A high volume plant may bring excess profits in the short run but will be costly to own and maintain if volume must be decreased because of market conditions. All of this points up the importance of the interaction between demand and location, and demonstrates the necessity of a thorough market analysis over the location planning horizon. The aim of this analysis would be to determine the expected demand from each feasible location over the short, medium and long terms. Actual distances and existing freight structures can be used for estimating price level and market share. The expected demand will determine the size of plant to be built and whether or not future expansion or cutbacks may be required. With this information, unit costs can be determined and the relationship between fixed and variable costs analysed. Where uncertain future demands exist, a decision tree model can be developed. This extension of the basic method will be discussed in Part III of this paper. For the present, it is envisaged that a market analysis, from each feasible location, will produce enough data to develop unit costs and to establish the relationship between fixed and variable costs for each location. Annual costs are then plotted against volume to determine the location with the lowest cost at the expected volume.

In this way the effect of demand is taken fully into account inasmuch as it affects the expected volume of the operation and hence unit costs. The location with the best relationship between fixed and variable costs at the expected volume will also become apparent when costs for different locations are shown on the same graph as illustrated in Figure 12 on page 77. If less than 2400 units per annum are to be produced, Location A is obviously the best choice; however, if more than 2400 are to be produced, location E dominates the others.

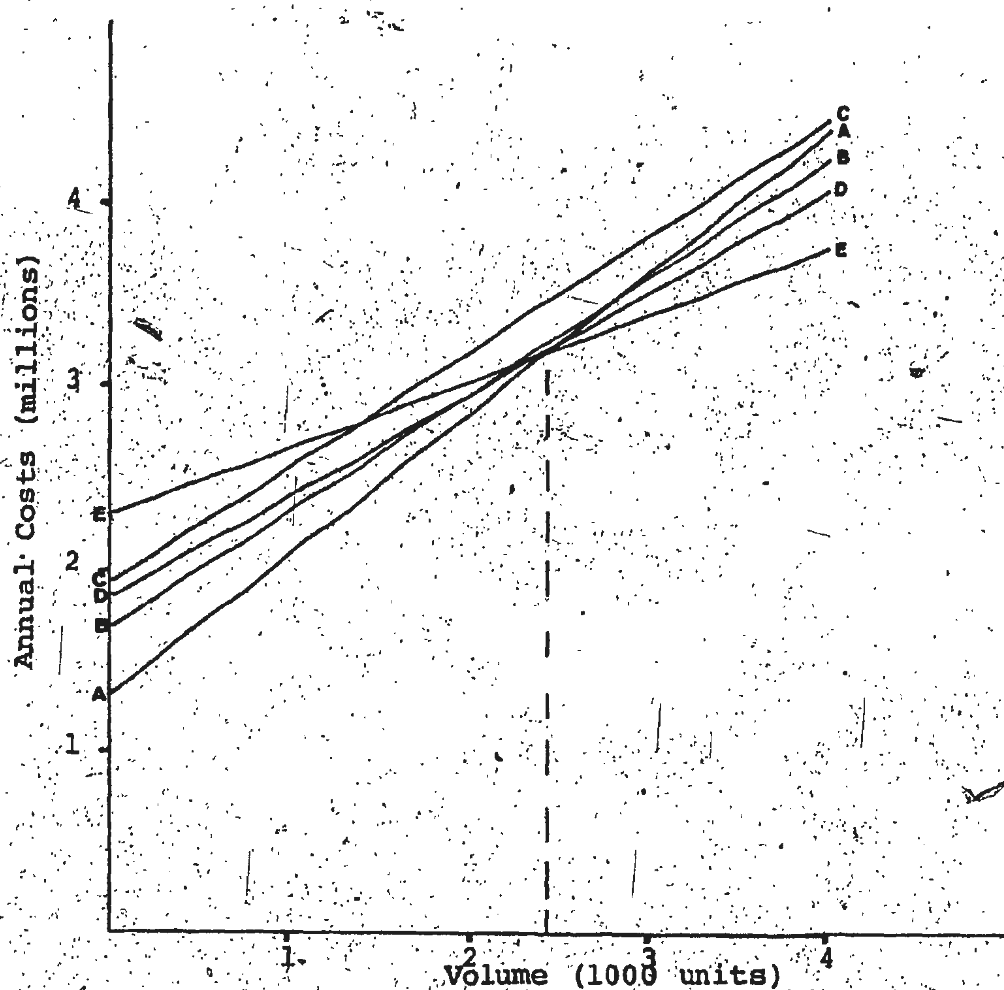

Figure 12 - Fixed and Variable Costs in Location Decisions

If, in this case, location A is chosen, expansion will be much less profitable than if location E had been chosen. On the other hand, if volume drops below 2400 per annum, the location with the lowest fixed costs becomes the most desirable. Clearly then, the expected volume is important when making a location decision.

The concepts used in assessing the interaction of location and demand are conventional - a market analysis over the planning horizon to establish expected demand for each feasible location; unit costs based on data from the variance analysis for each location; and a comparison of locations based on fixed and variable costs at the contemplated production volume.

Chapter 10

The Proposed Method Summarized and Illustrated

In summary, the steps which should be taken in performing a location analysis are as follows:

CRITICAL VS. NONCRITICAL FACTORS

1) Determine the critical factors for the industry under consideration.

2) Using these critical factors determine which region or regions have acceptable locations. Include one or more regions having established locations.

VARIANCE AND RELATIVE FACTOR SIZE

1) Determine which additional noncritical factors are to be considered. List all factors under the headings tangible, intangible and personal.

2) Develop annual cost equivalents by location for each factor using the suggested methods for intangible and personal factors.

3) Compute the standard deviation for each factor to be considered.

4) Determine the locational weight for each factor in proportion to the locational variance ratio.

5) Compute the product of the expected annual equivalent cost for a specific factor and the locational variance ratio for this factor.

6) Sum these products for each location, including existing location(s).

7) Select those locations with lowest totals of weight-cost products and compare to totals for existing locations.

8) All locations close to or lower than existing locations are feasible and should be considered carefully. If all are substantially higher than existing locations, the likelihood of competing

successfully is remote. In this case, new alternative locations should be found, if possible, before continuing in the analysis.

DEMAND AND MARKET SHARE

1) Perform a market analysis over the minimum planning horizon (short, medium, and long term) to estimate the expected demand at each feasible location.

2) Compute the unit cost at each feasible location using the data developed for the analysis of variance. Distinguish between fixed and variable costs.

3) Plot the expected equivalent annual costs against volume for each feasible location.

4) Select that location which has the most attractive relation between fixed and variable costs at the volume contemplated. Consider at this stage the expected volume in the medium and long terms.

10.1 Location Factors

The question as to what factors should be considered in performing a location analysis is important. Location guidelines tend to be quite detailed and it is not uncommon to find in excess of one hundred separate factors. This is in sharp contrast to pure location theories where one or, at most, three, overriding factors are considered. Weber, for example, bases his theory largely on transportation and introduces the modifying influences of labour and agglomerative forces to explain actual locations. Rawstron has an interesting viewpoint on this question.[1]

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[1] E.M. Rawstron, "Three Principles of Industrial Location", Institute of British Geographers, Vol. 25, 1958, pp. 135-42

He argues that the cost structure of an industry may be broken down into five basic categories - namely labour, materials, land, marketing and capital. He recognizes that these divisions mean different things in different industries and that in studying the cost structure of a particular industry these broad divisions would need further subdividing. However, he points out that power is included under materials or land and transport is an attribute of one or more of materials, labour, land and marketing. It is quite conceivable that transport costs would contribute to all of these components of the cost structure. This may therefore be a more realistic way of looking at the effect of transportation on overall costs than listing transportation as a separate discrete cost.

Rawstron further argues that locational cost should not be identified as a separate entity, although this is theoretically possible. Rather, that part of each component of the cost structure attributable to location should be identified. This is consistent with the method developed in this paper where each factor is weighted in strict accordance with its contribution to the total locational variance of all costs. Rawstron recognized the importance of the locational variance of costs and the relationship between that variance and the relative size of the cost component. He noted these two important points:

(i) The larger the share within the cost structure of the basic cost (i.e. without the addition of locational cost) of a component, the more important is its locational cost likely to be and vice versa.

(ii) A large variation from place to place in the locational cost of a component is likely to be more important than a small variation.

These two considerations should not, however, be taken independently of each other.[1]

Rawstron stopped short of explicitly relating locational variance and the relative size of the cost component in the total cost structure. Because Rawstron did establish this important relationship, his viewpoint is adopted and developed here. Locational variance and relative cost are explicitly related through the concept of weighting locational factors according to their contribution to total locational variance. Other point rating methods do not use locational variance in determining weights.[2,3,4]

A detailed subdivision of cost factors, or the broad divisions of Rawstron can be used. However, a moderate amount of detail is required. Certainly no factors contributing to locational costs can be overlooked. Either they must be listed separately or considered within a broad cost component such as labor or marketing. It is important that

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[1] Ibid, p. 138

[2] L.J. Rago, Casebook in Production Management, International Textbook Co., 1963, pp. 420 - 428

[3] P.A. Brown and D.F. Gibson, "A Quantified Model for Facility Site Selection - Application to a Multiplant Location Problem", AIIE Transactions, Vol. 4, No. 1, 1972 pp. 1 - 10

[4] M.K. Starr, Production Management, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1972, pp. 330 - 352

whatever convention is adopted be applied consistently for each location. Power cannot be considered as a separate factor at location A and as part of land costs at location B. Clearly one or the other approach must be used consistently throughout the analysis.

It is also important that a location analysis be as complete as possible from the costs point of view. If the principle of including all costs is used, the likelihood of overlooking an important factor is greatly reduced. Also, the danger of missing hidden costs is minimized. For example, an industry requiring the use of large quantities of clean, fresh water may be tempted to assume that this commodity is available everywhere at a low nominal cost. A cost comparison will likely reveal that considerable differences exist with respect to quantity, quality and cost. Similarly it may be assumed that because labour is unionized the cost will be identical everywhere. Not only will basic rates differ but skill, efficiency and attitude will have a pronounced effect on total labour costs. These differences must be identified for an effective location analysis.

10.2 An Illustrative Example

Suppose an experienced firm in a particular industry is planning to open a new plant because of expansion requirements or excessive costs at the existing location.

It has been decided to look objectively for the best location to build or buy a new plant. A search and evaluation team is formed and includes people technically experienced in the industry and fully familiar with the financial structure of the industry. Usually such people will be available within the firm but, if not, it is imperative that suitable expertise be called in. An important consideration in location analysis is the ability to be able to generate and identify alternative courses of action. Empirical location studies show that top level executives are not usually adept at generating alternatives.[1] They are most effective, on the other hand, in choosing from a set of alternatives that have been evaluated and assessed by a lower management stratum. Engineers are frequently involved in the process of identifying and evaluating alternative courses of action and their professional training in technical areas makes them particularly suitable as members of a search and evaluation team for location analysis.

The team will first of all identify the critical factors for the industry. An analysis of the basic components of the cost structure may help to determine which factors are critical. For example, if materials account for thirty per cent of all costs, then materials costs will be

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[1] Söderman, Industrial Location Planning, 1975, p. 168

critical. Suppose the existence of specific raw materials, reliable power and semi-skilled labour are the critical factors. A regional study at this stage shows that there are eight locations which meet the minimum requirements in terms of quality and quantity. These locations may be dispersed throughout several regions or they may be all located in the same region. At this stage it should also be determined whether or not the proposed industry is environmentally and socially acceptable to the regions involved. These concerns could be critical in the sense that the industry may simply be unacceptable to those regions.

Besides the eight alternative locations with development potential two existing locations are included for comparison purposes. Since these locations cannot be selected, their locational variance will be computed only to indicate whether or not the other potential locations are economically feasible. They are identified by an asterisk in the analysis of the relevant costs for all factors at each location.

At this point the analysis shifts to an examination of variance. All factors contributing cost to the product must be identified. Intangible and purely personal factors, if applicable, must also be included. A personal factor might be that the selected location be within a minimum distance of a golf course or that the local weather be pleasant and dry. Obviously, if such concerns are to be considered, specific minimum requirements relating to them must be set down. If a location is eliminated because of such a requirement, the lost profit potential attached to such a decision can be established.

Location incentives, if available, should be applied against the appropriate factor for each location. For example, if government subsidizes labour to encourage the growth of jobs, this subsidy should be applied against the expected annual labour cost. If power subsidies are available, the cost of power will be reduced. A capital grant will reduce the capital requirement from the firm's own resources. Transportation subsidies will reduce the transport costs and so on. The important point about subsidies is that they are usually time related and expire at a given point in time. For this reason it is important that subsidies be converted to annual equivalents over the minimum planning horizon. The situation of an industry relying for its very existance upon government subsidy is undesirable. When such subsidy is withdrawn, or in many cases, simply not increased, the industry will bankrupt. However, if subsidies are converted to annual cost equivalents and applied against the appropriate cost factor, they can be realistically incorporated into a locational analysis.

The factors listed in Table 1, page 87, are illustrative only and are, in no way, meant to be the best or all inclusive

TABLE 1

EXPECTED ANNUAL COST EQUIVALENTS AT EACH LOCATION ($1000)

FACTORS	A	B	C*	D	E	F	G	H*	I	J
MATERIALS	360	400	390	410	365	370	405	415	440	380
POWER	108	93	100	160	114	85	105	94	122	130
LABOR	639	807	696	651	755	730	712	682	644	750
LAND AND BUILDINGS	541	366	420	612	435	701	604	656	712	557
TRANSPORTATION	412	410	406	452	390	404	408	412	415	431
CAPITAL	1120	1081	998	1112	1016	1043	1126	998	1062	1214
INSURANCE*	034	061	035	052	026	042	081	053	064	044
SECURITY	065	031	074	042	061	053	028	044	051	048
MARKETING	274	291	330	324	289	266	301	287	269	308
INTANGIBLE FACTORS										
CLIMATE	040	020	080	060	040	060	020	040	060	040
LABOUR CLIMATE	200	300	100	300	200	400	300	400	500	100
COMMUNITY ATTITUDE & SERVICE	060	000	120	060	180	120	240	000	240	180
ENVIRONMENTAL ACCEPTABILITY	050	250	200	100	150	050	250	200	150	050
PERSONAL PREFERENCES										
TOTALS	3903	4110	3949	4335	4021	4324	4580	4281	4729	4232

set. The level of detail thought necessary in breaking down the cost structure of an industry for locational analysis is a function of the industry itself and the firm's desire for detail. Similarly, the number of intangible factors to be considered will be more or less, depending on the firm's desire to use such factors in a quantitative analysis.

An intangible factor such as labour climate is a very real consideration for the successful operation of an industry requiring a high labour input. In the example, the expected annual cost equivalents, arising out of labour climate, range from $100,000 to $500,000, corresponding to the five discrete levels described in Table 2 on page 89. No location was thought to have an ideal labour climate possibly contributing to profit or at least contributing no costs to the balance sheet.

Each potential location is then assigned to one of these discrete levels. Of course, the cost of each level depends on the volume of production and the relative size of the labour component for the industry. The costs could be scaled back so that the best locations are seen as contributing zero costs but this would distort the true picture somewhat. Similar level descriptions are developed for all intangible factors and annual cost equivalents are assigned to them.

When all costs have been identified and tabulated, the standard deviations for all factors can be computed. This

TABLE 2

EVALUATION OF INTANGIBLE FACTORS

	Cost
Labour is hostile and antagonistic. The number of days lost to strikes is much higher than the national average. Wildcat strikes are common. Absenteeism is a severe problem. Productivity is low.	$500,000
Labour is reactionary. Days lost to strikes is greater than national average. Wildcats are uncommon. Absenteeism prevalent. Productivity is poor.	$400,000
Labour doesn't co-operate but is passive in attitude. Days lost to strikes about equal to the national average. Wildcats are rare. Absenteeism and productivity are average.	$300,000
Labour co-operates with management. Days lost to strikes less than national average. No history of wildcat strikes. Absenteeism and productivity better than national average.	$200,000
Labour actively co-operates with management. Days lost to strikes much less than national average. No history of wildcat strikes. Absenteeism is not a problem. Productivity is much better than average.	$100,000
Labour climate is ideal. No days lost to strikes. Absenteeism is insignificant. Productivity is very high.	$0

is done in Table 3, page 90. It may also be useful to plot costs for all factors on a bar chart; this gives a good graphical representation of costs and immediately shows the amount of locational variance for each cost factor.

TABLE 3

LOCATIONAL FACTOR VARIANCE

FACTORS	STANDARD DEVIATION σ_i x \$1000	RATIO OF TOTAL $\sigma_i / \Sigma \sigma_i$
MATERIALS	25.3	.037
POWER	22.0	.032
LABOUR	55.0	.081
LAND AND BUILDINGS	120.2	.177
TRANSPORTATION	16.8	.025
CAPITAL	68.2	.100
INSURANCE	16.5	.024
SECURITY	14.5	.021
MARKETING	21.9	.032
CLIMATE	19.0	.028
LABOUR CLIMATE	131.7	.194
COMMUNITY ATTITUDE AND SERVICES	89.4	.131
ENVIRONMENTAL ACCEPTABILITY	79.8	.117
TOTAL ($\Sigma \sigma_i$)	680.3	1.000

Sample calculations are included in Appendix 3, page 130 for the entries in Table 3. Table 1 may now be reproduced and the cost of each factor at each location is multiplied by the appropriate factor variance ratio from Table 3, page 90. The results are shown in Table 4, page 92. Sample calculations are included in Appendix 3.

In Table 4, the products are shown in brackets below the cost entries and the sums are shown at the bottom. It can be seen immediately that although Location A has the lowest total of expected annual cost equivalents, it is not superior to location C (an existing location) when the variance of locational factors is taken into account. Nonetheless, Location A does have the lowest total of weighted cost factors of all potential locations with a product sum of 351.4. This is higher than Location C which has 332.0,but lower than Location H (an existing location) with 413.3. Location B (366.0), Location D (395.8), Location E (358.9) and Location J (371.9) all have weighted cost factors less than existing location H. The total of weighted cost factors is not an absolute value but only has meaning as a relative measure of the locational variance of costs.

On the basis of this analysis, Locations A, B and E would appear to be very close in terms of expected annual costs. In order to choose several of these alternatives for further consideration, it is now necessary to distinguish between fixed and variable costs at these locations and

TABLE 4

EXPECTED ANNUAL COST EQUIVALENTS AT EACH LOCATION ($1000) MULTIPLIED BY FACTOR VARIANCE RATIOS

	A	B	C*	D	E	F	G	H*	I	J
MATERIALS	360 (13.3)	400 (14.8)	390 (14.4	410 (15.2)	365 (13.5)	370 (13.7)	405 (15.0)	415 (15.4)	440 (16.3)	380 (14.1)
POWER	108 (3.5)	93 (3.0)	100 (3.2)	160 (5.1)	114 (3.6)	85 (2.7)	105 (3.4)	94 (3.0)	122 (3.9)	130 (4.2)
LABOUR	639 (51.8)	807 (65.4)	696 (56.4)	651 (52.7)	755 (61.2)	730 (59.1)	712 (57.7)	682 (55.2)	644 (52.2)	750 (60.8)
LAND AND BUILDINGS	541 (95.8)	366 (64.8)	420 (74.3)	612 (108.3)	435 (77.0)	701 (124.1)	604 (106.9	656 (116.1)	712 (126.0)	557 (98.6)
TRANSPORTATION	412 (10.3)	410 (10.3)	406 (10.2)	452 (11.3)	390 (9.8)	404 (10.1)	408 (10.2)	412 (10.3)	415 (10.4)	431 (10.8)
CAPITAL	1120 (112.0)	1081 (108.1)	998 (99.8)	1112 (111.2)	1016 (101.6)	1043 (104.3)	1126 (112.6)	998 (99.8)	1062 (106.2)	1214 (121.4)
INSURANCE	034 (0.8)	061 (1.5)	035 (0.8)	052 (1.2)	026 (0.6)	042 (1.0)	081 (1.9)	053 (1.3)	064 (1.5)	044 (1.1)
SECURITY	065 (1.4)	031 (0.7)	074 (1.6)	042 (0.9)	061 (1.3)	053 (1.1)	028 (0.6)	044 (0.9)	051 (1.1)	048 (1.0)
MARKETING	274 (8.8)	291 (9.3)	330 (10.6)	324 (10.4)	289 (9.2)	266 (8.5)	301 (9.6)	287 (9.2)	269 (8.6)	308 (9.9)
INTANGIBLE FACTORS										
CLIMATE	040 (1.1)	020 (0.6	080 (2.2)	060 (1.7)	040 (1.1)	060 (1.7)	020 (0.6)	040 (1.1)	060 (1.7)	040 (1.1)
LABOUR CLIMATE	200 (38.8)	300 (58.2)	100 (19.4)	300 (58.2)	200 (38.8)	400 (77.6)	300 (58.2)	400 (77.6)	500 (97.0)	100 (19.4)
COMMUNITY ATTITUDE & SERVICES	060 (7.9)	000 (0)	120 (15.7)	060 (7.9)	180 (23.6)	120 (15.7)	240 (31.4)	000 (0)	240 (31.4)	180 (23.6)
ENVIRONMENTAL ACCEPTABILITY	050 (5.9)	250 (29.3)	200 (23.4)	100 (11.7)	150 (17.6)	050 (5.9)	250 (29.3)	200 (23.4)	150 (17.6)	050 (5.9)
PERSONAL PREFERENCES										
TOTAL COSTS	3903	4110	3949	4335	4021	4324	4580	4281	4729	4232
TOTAL (WEIGHTED COST) FACTORS	(351.4)	(366.0)	(332.0)	(395.8)	(358.9)	(425.5)	(437.4)	(413.3)	(473.9)	(371.9)

compare them at the expected production volume. Of course, all potential locations should be brought into the next phase of the analysis. If, for example, one or more locations were eliminated in order to meet personal preferences, it would still be advisable to consider these locations in order to know how costly meeting such requirements will be.

Suppose the fixed and variable costs at the various locations are determined as shown in Table 5 below.

TABLE 5

FIXED, VARIABLE AND TOTAL COSTS AT EACH LOCATION ALTERNATIVE

LOCATION	FIXED COST ($)	VARIABLE COST ($) @ 30,000 Units	TOTAL COSTS ($)
A	1,500,000	80.1	3,903,000
B	1,700,000	80.3	4,110,000
C*	1,400,000	85.0	3,949,000
D	2,000,000	77.8	4,335,000
E	1,800,000	74.0	4,021,000
F	1,600,000	90.8	4,324,000
G	2,100,000	82.7	4,580,000
H*	1,900,000	79.4	4,281,000
I	1,550,000	106.0	4,729,000
J	1,850,000	79.4	4,232,000

These fixed and variable costs are plotted against volume in Figure 13, page 95. When costs are shown in this way it is easy to see the relative advantage of each location. Location A is superior if the production is expected to remain less than about 50,000 units per annum. However, Location E, although it has relatively high fixed costs, is superior at higher volume. If the contemplated volume is expected to exceed 50,000 units per annum, Location E is the best overall location.

If, because of personal preferences, Location E is eliminated, the alternative of incurring higher variable costs at Location A can be assessed. In like manner, any two alternatives can easily be compared, and the incremental cost of adopting any alternative over a cheaper one can be determined.

In any industry where fixed and variable costs are indistinguishable, the relative importance of the analysis at the previous phase is increased. The important point is that when locational costs are presented in this manner it is easier to identify profit maximizing alternatives. Needless to say, it is extremely important that good estimates of fixed and variable costs be obtained.

A necessary condition, when locations are compared by analysis of fixed and variable costs, is that these costs must be determined at the volume range expected, at least in the short term (5 years). Significant volume changes

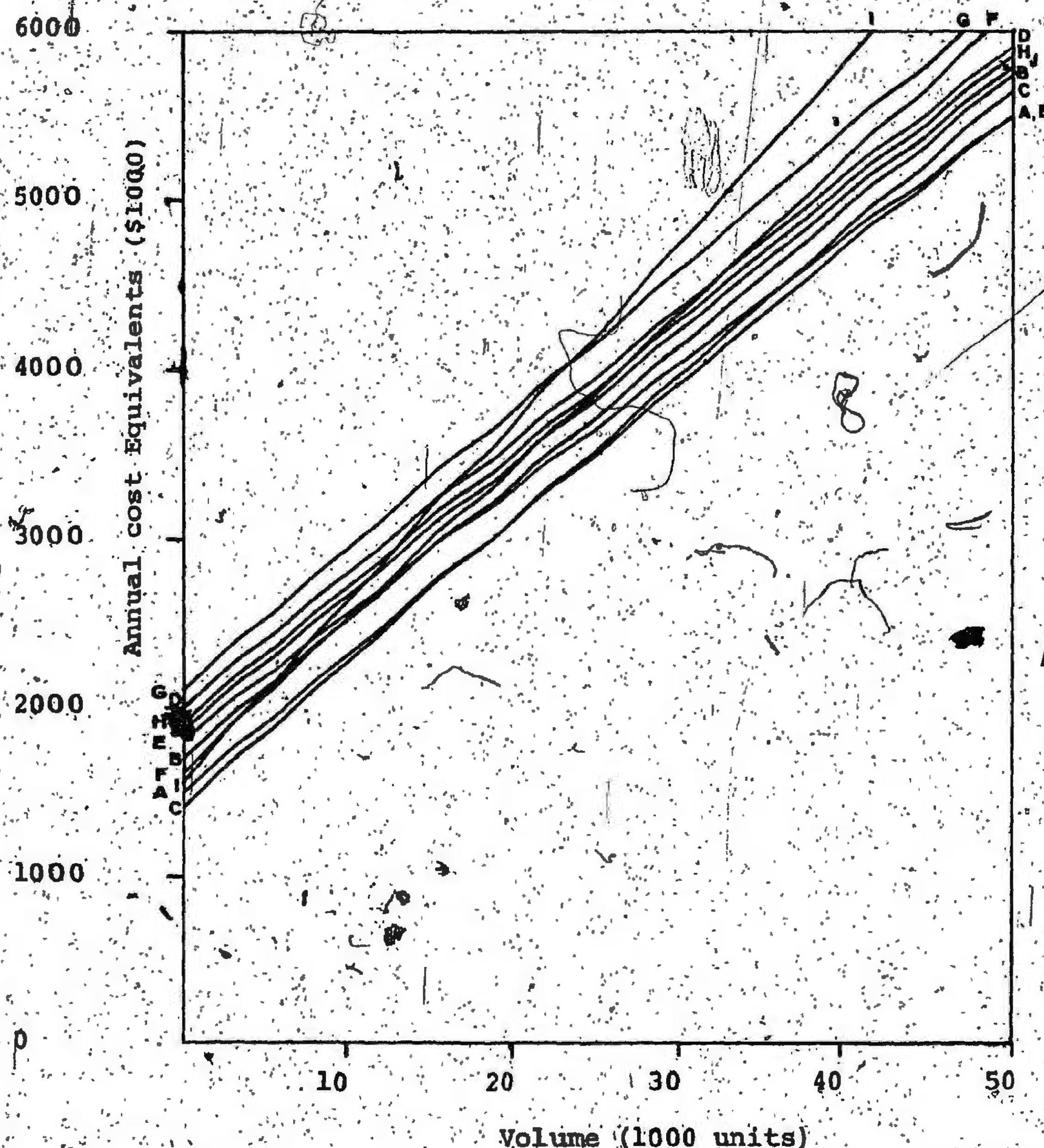

Figure 13 - Fixed and Variable Costs at each Location Alternative.

will change the distribution of fixed and variable costs. The same conditions apply to demand. If demand changes significantly by location, the expected demand should conform to the design production volume. It is not necessary or even likely that volume remain constant over all locations.

The purpose of this example has been to illustrate:

1) how critical location factors must be accounted for

2) how costs can be analysed by locational variance using the standard deviation as a weighting factor

3) how volume and demand considerations affect costs at different locations

4) how these three locational concerns can be analysed using conventional methods to choose one or more alternatives in order to maximize profits and meet other specified requirements.

The final choice of location should be made only after the selected alternatives are investigated thoroughly to confirm estimates and make sure the industry is compatible with the communities.

In this example, locations A and E are quite close in all respects and both are superior to location C at high volumes. Since C is an existing location this strongly supports the choice of one of these alternatives.

PART III

SPECIAL APPLICATIONS AND EXTENSIONS

Chapter 11

The Regional Problem

Part II of this paper developed a procedure for evaluating alternative locations for an industry. In this part some special applications and extensions of the basic method are discussed.

The location problem is usually thought of in terms of an industry seeking the optimal or suboptimal location from which to operate. An equally important problem and perhaps a more vital one from the social point of view is that of a region seeking an industry. This is commonly thought of as the regional problem, although in reality the regional problem is broader; whether or not development is to take place at all must first be answered. Included in this are the important questions of what kind of development and how much. These are interrelated concerns and cannot be assessed independently.

In general, however, it would be true to say that most regions wish to develop but are less certain about how the development is to proceed and to what extent. Most regional governments are committed to some development and are actively pursuing policies which promote development. Their objective is to increase the prosperity of the region and its inhabitants by attracting industry. This creates more jobs and adds to the economic well being of the region. More public services can be provided through taxation and, generally speaking, the standard of living is increased.

Three concerns which should be considered when evaluating the suitability of an industry for a specific region are its environmental acceptability, its social acceptability and its economic feasibility.

In recent years environmental acceptability has become critically important in locating an industry. This has happened because of a growing awareness that what we discharge into the natural environment through industry and other sources has a cumulative detrimental effect, not only on the environment of the specific region where the industry is located, but also on the larger scale systems. These detrimental effects are often permanent once they take place but usually they can be controlled within specified desirable limits at some cost to the industry and ultimately the consumers. Two important points should be noted with respect to environmental acceptability: First of all, regions already heavily industrialized may reject new industry forcing it to seek other regions where a location premium will have to be paid. These regions may be less wary of environmental problems and a government anxious to attract industry may overlook environmental concerns; secondly, the solution to environmental problems in the form of improved technology to treat waste so that it is environmentally acceptable, increases costs on the balance sheet. Therefore it can be expected that industry will resist such requirements or at best conform to the minimum standards imposed. For these reasons, developing regions should move cautiously when evaluating potentially new industry.

An industry's social acceptability should also be considered by the developing region. In general, will the new industry add to or detract from the social welfare of the region? More specifically, will the right kind of employment be generated or will outside workers migrate in? Will a rapid expansion of social institutions in such areas as education and health be required? Will a new labour requirement have a negative effect on existing industries? Will new services such as port facilities be required? Will undue pressure be brought on existing services such as transport systems, waste collection and disposal systems and power distribution systems? Will the new industry be accepted in the community? These and other questions affecting the social acceptability of a new industry should be answered.

The economic feasibility of an industry should be assessed by the region in which the industry plans to locate. The usual practice has been for the region to trust the industry and accept its statements in good faith. After all, if an industry is likely to fail after a short operation period, why would its principals establish it in the first place? Regardless of the appeal of this reasoning, experience has shown that some major location decisions have been made without proper assessment of all locational factors. Governments eager for industrial development can be misled by unscrupulous promoters. One or two years later, after some costly construction, operational difficulties prove insurmountable or the market collapses.

The damage caused by such failures is immense. Besides the cost of facilities and construction, untold personal and community damage is caused from both the social and economic points of view. Any check which could reduce the likelihood of such enterprises ever getting started would be worthwhile. Since this problem is the inverse of the location problem, it would seem plausible that a similar analysis could be conducted from the regional point of view.

In this case, a region would begin by identifying its natural resources or other advantages which would be seen as critical location factors by an industry. The emphasis here should be kept on natural advantages such as raw materials deposits, cheap reliable power, labour and markets. The availability of sites and services, although important, should not be allowed to mask critical factors. Generally speaking, if a region is suitable for a particular industry, an acceptable site can be found and if existing services are not adequate they can be improved. However, if some critical concern such as raw material supply or market is overlooked or inadequately assessed, no amount of backtracking can fix it. In this regard regions should realize that they can do nothing about the distribution of natural resources and should therefore concentrate on locational factors they can affect such as taxes and community services.

Using this approach a region can develop a list of suitable potential industries. There is no reason why the method of selecting a potential location based on the locational variance of cost factors cannot be used by a region to highlight its advantages over other regions. Such an analysis would also reveal whether or not an industry locating in the region would likely be successful. This is especially true if existing locations are also brought into the analysis.

If an industry is serious about locating in a region it will not be averse to releasing its cost data to regional authorities. These can then be checked against the region's own data. In the final analysis market and demand considerations can be introduced by computing fixed and variable costs at the anticipated volume.

If this method is carefully applied by a region to assess potential industries, the likelihood of incurring a major bankruptcy with all its adverse effects can be significantly reduced or even eliminated entirely. The two concerns discussed earlier - environmental acceptability and social acceptability can be assessed in a manner similar to that suggested for the evaluation of intangible factors in Part III. From the regional point of view, however, it is likely that these two concerns would have the effect of eliminating industries from consideration. Supposing, however, that an industry is socially and environmentally acceptable, within specified desirable limits, it is still necessary to compute the expected annual cost equivalents that meeting these limits will add to its balance sheet. Also, there may be some costs which the region will have to absorb in the areas of social and municipal services to new industry.

Chapter 12

Uncertainty in Location Decisions

Many decisions regarding the construction of new facilities and the expansion of existing facilities must be made with uncertain information. The actions of a rival, the expansion or decline of the market, changing population patterns and changes in government are all areas giving rise to uncertainty. In spite of the uncertainty, a decision must be made even if the decision is to take no action at all.

A useful technique for analysing decisions with uncertain outcomes is to arrange the various decisions and their outcomes in a decision tree. A simple example will be used to illustrate the technique but more complicated problems can be analysed.[1,2,3] The situation is presented graphically in Figure 14 on the next page.

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[1] J.F. Magee, "Decision Trees for Decision Making", Harvard Business Review, Vol. 42, July-August 1964, pp. 126 - 138.

[2] J.F. Magee, "How to use Decision Trees in Capital Investment", Harvard Business Review, Vol. 42, Sept.-Oct. 1964, pp. 79 - 96.

[3] R.F. Hespos and P.A. Strassmunn, "Stochastic Decision Trees for the Analysis of Investment Decisions", Management Science, Vol. II, No. 10, 1965, pp. 244 - 259.

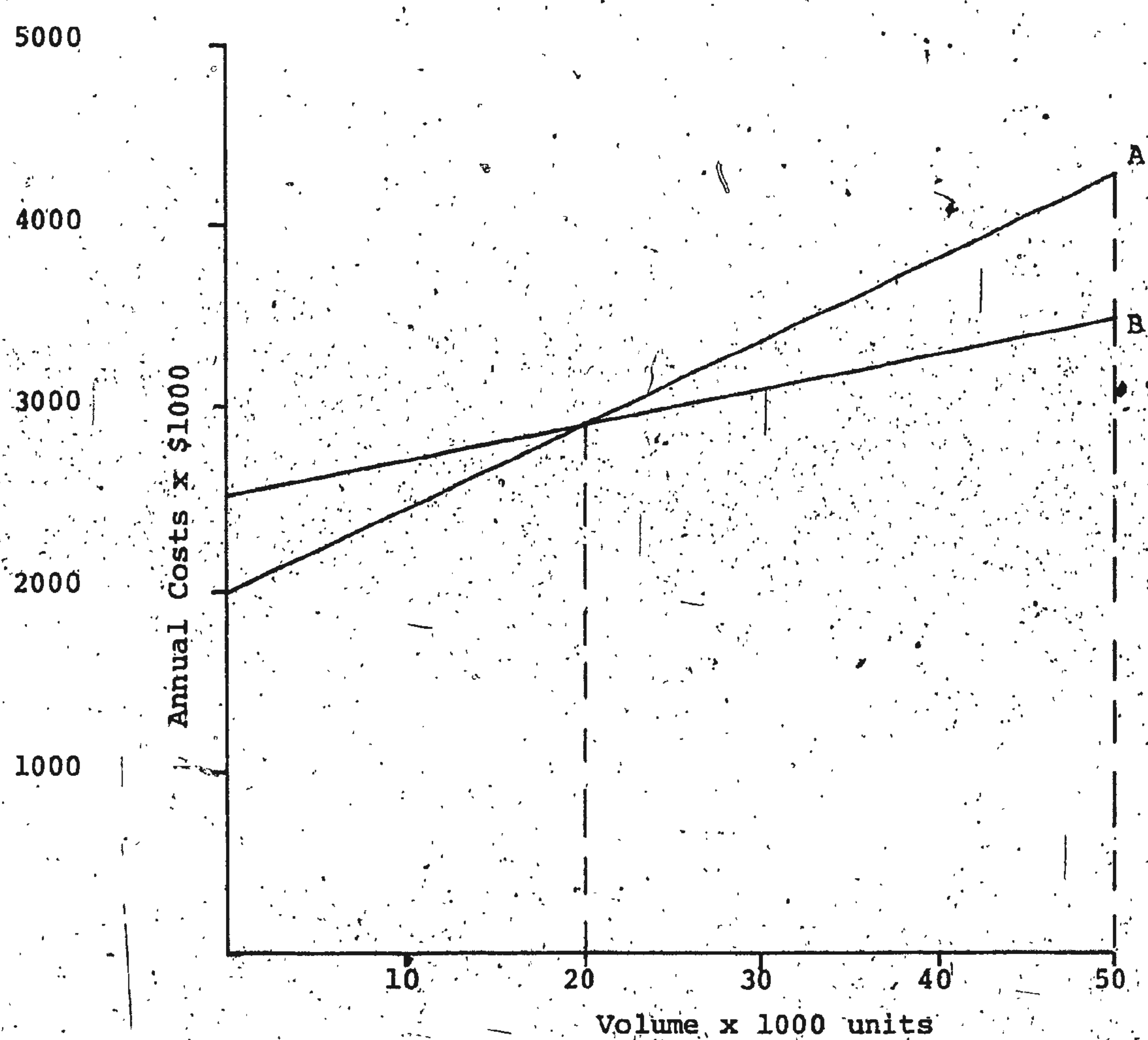

Figure 14 - Breakeven volume for two location alternatives

Fixed Costs (A) $2,000,000 per annum
Variable Costs (A) $45/unit
Fixed Costs (B) $2,500,000 per annum
Variable Costs (B) $20/unit

If it is known with certainty what volumes will be demanded over the fifteen year planning horizon, the decision is clear. However, estimates of future demands are never certain.

Suppose the market forecast shows that the demand and associated probabilities over the fifteen year planning horizon are as tabulated below.

TABLE 6

UNCERTAINTY IN DEMAND[1]

DEMAND[1]		PROBABILITY
1st 5 years	next 10 years	
50,000	50,000	0.5
50,000	20,000	0.1
20,000	20,000	0.4
20,000	50,000	0.0

The decision to locate at A or B and the possible outcomes can be represented by a simple decision tree.

[1]Such demand estimates could be associated with the expected actions of a rival.

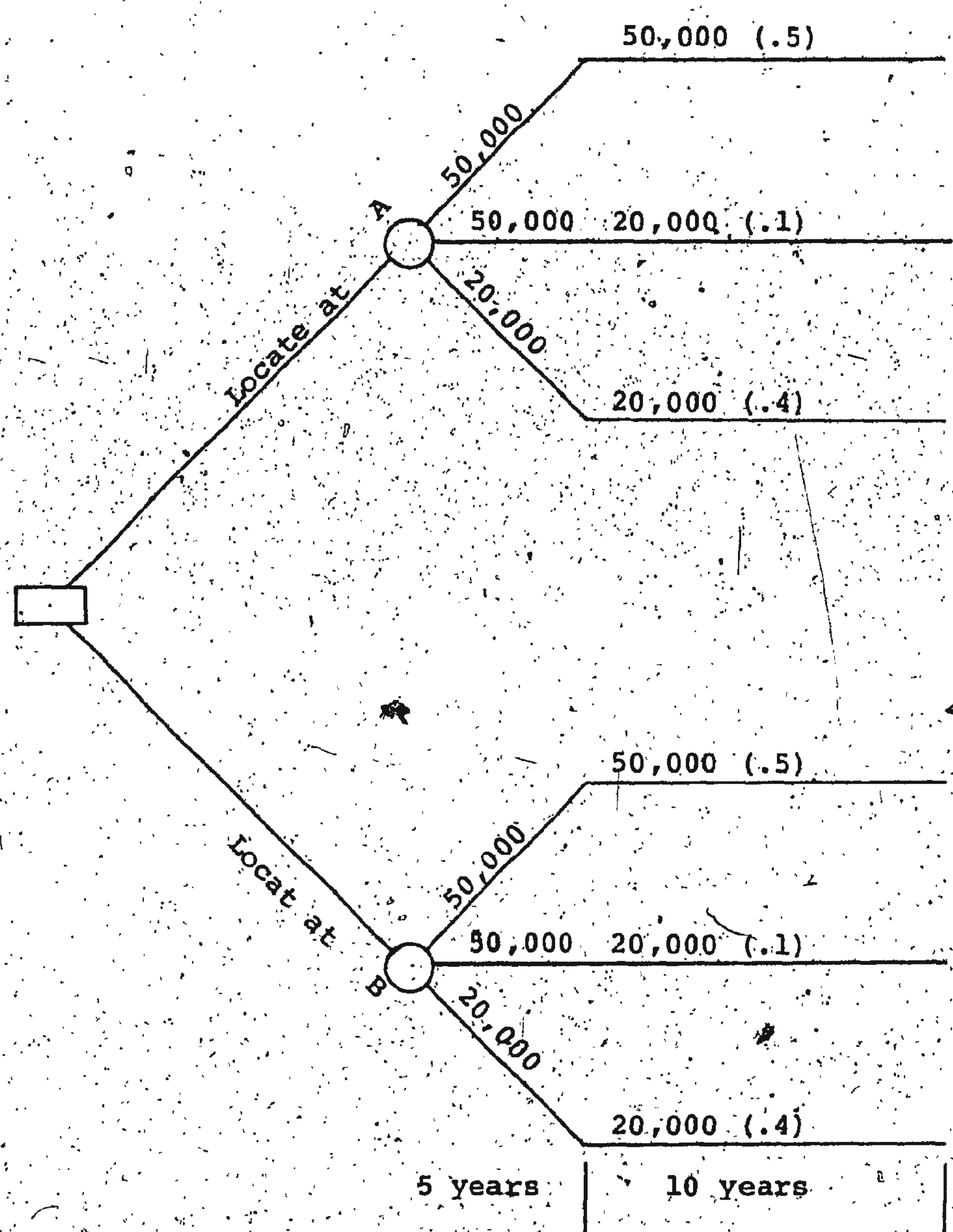

Figure 15 - Decision Tree for Location Decision with Uncertain Demand

Total outlay over the fifteen year period can now be computed for each demand outcome and converted to expected present values. An interest rate of 10% is assumed. These calculations are summarized in Table 7 below. Expected value criterion is used to account for probability.

TABLE 7

EXPECTED PRESENT VALUES

LOCATION A

.5(2,000,000 + 50,000 x 45 @ 10% for 15 years)
\+ .1(2,000,000 + 50,000 x 45 @ 10% for 15 years)
\+ .1(2,000,000 + 20,000 x 45 @ 10% for 10 years)
\+ .4(2,000,000 + 20,000 x 45 @ 10% for 15 years)

Total Expected Present Cost 28,378,648

LOCATION B

.5(2,500,000 + 50,000 x 20 @ 10% for 15 years)
\+ .1(2,500,000 + 50,000 x 20 @ 10% for 5 years)
\+ .1(2,500,000 + 20,000 x 20 @ 10% for 10 years)
\+ .4(2,500,000 + 20,000 x 20 @ 10% for 15 years)

Total Expected Present Cost 25,242,070

This analysis shows that for the anticipated volumes total expected costs are minimized at Location B.

Other approaches to decision making with uncertainty are available. D.B. Hertz analyses risk with the aid of computer simulation.[1,2]

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1 D.B. Hertz, "Risk Analysis in Capital Investment", Harvard Business Review, Vol. 42, Jan.-Feb. 1964, pp. 95 - 106.

2 D.B. Hertz, "Investment Policies that pay off", Harvard Business Review, Vol. 46, Jan.-Feb. 1968, pp. 96 - 109.

1.[illegible]1 Computer Applications

It is easy to see that the mechanical elements of this method - that is, the calculation of standard deviations, variance ratios and product weights can be handled by a computer. However, the calculations are so simple that it is unlikely a firm would wish to use a computer. Obtaining inputs in the form of expected annual costs at each location is certainly the most difficult and time consuming requirement; here a computer will not help. It is intuitively felt that location decisions are so important and taken so infrequently by an individual firm that it would not be advisable to trust the process to a computer. Of course, for an individual or firm assisting others in evaluating location alternatives, a computer could be of great assistance in performing routine calculations. Such an organization might also develop comparative costs lists for various services and materials in different regions. This data could be stored in a computer and updated periodically according to price index changes, lending rate changes and other price indicators. Here a computer could be utilized effectively. However, it was not felt that a computer model was justified for the development and illustration of the concepts used in the proposed method of evaluating location alternatives.

APPENDIX 1

PLANT SITE SELECTION GUIDE[1]

1. LABOR HISTORY

Does labor force have deep community roots? ___ ___

Do most workers own their homes? ___ ___

Is labor force largely transient? ___ ___

Can you determine prospects of future labor tranquility as evidenced by convenient indexes such as labor turnover of absenteeism? ___ ___

Has labor history been satisfactory? ___ ___

Does one union dominate the area? ___ ___

Does labor group maintain a good reputation for accepting technological change? ___ ___

Do employees have a good reputation for housekeeping practices and care of equipment? ___ ___

2. LABOR AVAILABILITY

Have you made a labor-availability survey? ___ ___
Typical factors:

a. Population at last census.
b. Population density per square mile.
c. Per cent agricultural.
d. Total employed in manufacturing.
e. Total employed in non-manufacturing.
f. Per cent men in labor force.
g. County-wide potential employment.
h. Unemployed available workers.
i. Shift willingness.
j. Distribution of available labor among skilled, semi-skilled, unskilled groups.
k. For women, average family income and whether basic need exists for supplemental income.

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[1]Plant Site Selection Guide, Factory Management and Maintenance, May, 1957.

Do farm areas serve as good labor pool? ___ ___

Is there a high degree of farm mechanization (which might affect availability)? ___ ___

Does community have an increasing supply of women seeking industrial jobs? ___ ___

Can you complement rather than compete with existing industry? (Example: Hire women from families of male employees.) ___ ___

Will seasonal jobs in nearby resort areas affect labor availability? ___ ___

Is community subject to other seasonal labor variations? ___ ___

Does adequate labor pool exist within reasonable radius? ___ ___

Are young people taking jobs elsewhere? ___ ___

Would better job opportunities keep them at home? ___ ___

Is work group well distributed among industrial, commercial, and service activities? ___ ___

3. INFLUENCE OF LOCAL INDUSTRY ON LABOR

Have you considered the principal community factors which will affect your proposed wage rates and working conditions? Typical examples: ___ ___

a. Wage rates, by skills.
b. Working hours.
c. Shift patterns.
d. Hourly or piece rates.
e. Fringe benefits.
f. Degree of competition for skills.
g. Pattern of year-end bonuses.
h. Degree of unionization.
i. Quality of union leadership.
j. Quality of union "followership."
k. Pattern of productivity.
l. Seniority provisions.
m. Layoff provisions.
n. Grievance patterns.
o. Presence of any unusual or radical tendencies (by either management or labor). ___ ___

Does industrial accident rate for community compare favorably with national averages? ___ ___

Will you be in direct (or indirect) competition with an industrial pace-setter? __ __

4. MATURITY OF CITIZENS

Do local civic and religious leaders have enlightened and progressive attitude toward business and industry (public, civic, commercial, religious, news, etc.)? __ __

Do people of community display political awareness? __ __

How many voters went to the polls in the last municipal election? __ __

How many voters went to the polls in the last national election? __ __

Do local people understand how business operates in the American economy? __ __

Do local citizens really encourage new industry? __ __

Are there community educational programs directed at young people? __ __

Do social and economic backgrounds of community point toward maturity? __ __

Is standard of living at or above the national average? __ __

5. MANAGEMENT POTENTIAL

Can prospective workers be expected to grow into added responsibilities? __ __

Can you translate evaluation into estimates for potential supervisors and executives? __ __

Can you expect to recruit certain management echelons locally? __ __

Are specialized skills available, such as scientific and technical manpower? __ __

Have local people responded well to in-plant training? __ __

6. ELECTRIC POWER

Can power system fill your needs (voltage, phase, cycles, capacity)? __ __

If relocating equipment do motor characteristics coincide with supply? ___ ___

Can distribution lines handle a plant expansion program? ___ ___

Is history of stoppages favorable? ___ ___

Is complete rate picture satisfactory? ___ ___

Are off-peak rates available? ___ ___

Do discounts and penalties apply? ___ ___

Are lighting allowances figured into rates? ___ ___

Are fuel adjustment clauses provided for in rate schedules of power companies? ___ ___

Are you planning to manufacture part or all of your own electric power? ___ ___

Will nuclear power be available? ___ ___

7. FUEL OIL

Is oil a competitive fuel in the area? ___ ___

Can you count on delivery regardless of method (pipe-line, tank car, tank truck, barge, tanker)? ___ ___

Will you need standby storage facilities? ___ ___

Do all component factors look favorable? (Tappable trunk line nearby, pipeline capacity, pumping capacity, rate picture, BTU content, proximity to gas fields, etc.?) ___ ___

8. NATURAL GAS

Is natural gas a competitive fuel in area? ___ ___

Is gas available on a firm basis? ___ ___

Are rates such that it is better to arrange for interruptible basis with standby fuel oil facilities? ___ ___

9. COAL

Is coal a competitive fuel in the area? ___ ___

Any problem about delivery? ___ ___

Have you considered costs of coal handling and storage facilities vs. competitive fuels? __ __

Do technological improvements in mining and usage help tilt the balance toward coal? __ __

Should lignite be considered? __ __

10. WATER SUPPLY

Are water requirements compatible with water resources? __ __

Is there an adequate public water supply? __ __

If you must exploit a private source, is the quantity adequate? __ __

Is quality satisfactory? __ __

If water treatment is needed, are costs in line with other site locations? __ __

If streams are the logical source, will the flow be adequate during dry months? __ __

Is the impact of future municipal and industrial users likely to be serious? __ __

If ground water is the source, are there legal restrictions on withdrawal and recharging rates of flow? __ __

Is there enough water to take care of growing trend towards air conditioning? __ __

Is incoming temperature of cooling water satisfactory? __ __

Are municipal authorities taking a long forward look at community water problems? __ __

Do technological improvements offer help in the water problem? __ __

11. WATER POLLUTION

Will you have waste disposal problems? __ __

Can streams nearby accommodate waste water? __ __

Will good business practice plus local or state ordinances call for waste treatment? __ __

12. RAIL TRANSPORTATION

Do groupings of major railroad systems take advantage of natural flow of traffic and thus minimize transfers? ___ ___

Is proposed location on or near the route of new crack merchandise trains? ___ ___

On a rate-blanketing basis are rates to principal markets satisfactory? ___ ___

Has pattern of differential freight rate increases been relatively favorable for your proposed area? ___ ___

Does railroad give transit or stop-off privileges for partial loading or unloading en route? ___ ___

For LCL type of shipping operations, are there ample freight forwarders or car loading companies? ___ ___

If more than one railroad serves area, do they have reciprocal switching arrangements? ___ ___

Are there adequate truck handling facilities at freight terminals? ___ ___

Is pick-up and delivery service available? ___ ___

Which of these principal physical rail considerations are important? ___ ___

a. Branch or main line.
b. Freight schedules.
c. Switchings per day.
d. Yard limits.
e. Direction of turnout to private siding from yard.
f. Orientation of site to roadbed.
g. Relative elevation of site and roadbed.
h. Potential construction difficulties, such as culvert, fill, bridge, cut.

Does prospective rail carrier favor the use of technologically improved equipment for meeting of shipper's needs? ___ ___

13. TRUCK TRANSPORTATION

For truck receipt and shipment operations, which of these factors are important: ___ ___

a. Natural traffic flow.

b. Specific routes.
c. Schedules
d. Rates.
e. Transfers.
f. Common, contract, or private carrier.

Is the site at or near a "trucking gateway" to reduce in-transit times? __ __

Are state laws as to truck size and weight restrictive? __ __

Will minimum weight restrictions by truckers affect you adversely? __ __

Are there good access roads, bridges, and culverts for trucks? __ __

Is the pattern of recent truck freight rate increases reasonable? __ __

Are state gasoline taxes in line with alternate sites? __ __

Can you use newest truck shipment techniques, such as "piggy-back" and "fishy-back"? __ __

Will the new Federal Highway Program help solve trucking problems? __ __

14. AIR TRANSPORTATION

If your product consists of high-grade commodities or expeditable merchandise, can you ship by air? __ __

Is site near a good airport? __ __

Are rates and schedules of scheduled air lines satisfactory for air shipment? __ __

Are good non-skeds available? __ __

Are there good air-freight forwarders nearby? __ __

Do needed air feeder lines exist, or promise to exist? __ __

Is airport service convenient for transport of personnel? __ __

Is there helicopter shuttle service, or (if not) can it be set up economically? __ __

15. WATER TRANSPORTATION

Is proximity to inland water transport important? __ __

Is proximity to overseas shipping important? __ __

Does area have an alert and progressive port authority of comparable commission? __ __

Are water transport rates and schedules competitive? __ __

Are port facilities closed down in winter? __ __

Is access to port convenient and economical? __ __

What about proximity to existing piers? __ __

Are construction costs a factor if new piers are needed? __ __

Is ample lighterage available? __ __

Do any special waterway advantages apply? (Example: "Scatrains" for loaded freight cars on ocean-going ships.) __ __

16. MISCELLANEOUS TRANSPORTATION

Is railway express service available? __ __

Is Air Express Division of Railway Express Available? __ __

Are pipelines usable as common carriers for you? __ __

Does prospective community have a desirable level of passenger transportation facilities (rail, bus, air) for serving employees and families, outside salesmen, visitors, etc.? __ __

Is employee transportation within the community adequate for your expected needs (commuter trains, street cars, buses)? __ __

Are there toll roads or toll bridges that will increase transport costs? __ __

Do winter conditions adversely affect transport? __ __

Does community have public or private warehouses available to help out with short-range inventory-storage problems? __ __

17. RAW MATERIAL SUPPLY

Are needed raw materials close enough? (Especially if perishables, bulky, or low in value). ___ ___

Will they be available, or are they committed to others? ___ ___

Are raw material sources reliable? ___ ___

Are the prices satisfactory? ___ ___

Are terms of sale and delivery right? ___ ___

Is cost of transport to site reasonable? ___ ___

Do you see evidence of depletion or shortage of resources (minerals, timber, soil, water, others)? ___ ___

Are there natural transportation transfer points nearby? ___ ___

Are suppliers of key parts or subassemblies close enough? ___ ___

Is rapid transportation from suppliers by truck or other means available? ___ ___

Are you close enough to key suppliers for easy consultantions? ___ ___

Are existing or proposed manufacturers nearby whose byproducts you can use? ___ ___

Are raw materials so remote that you must consider building homes and facilities for workers to attract them? ___ ___

Where large natural resources areas are needed (such as timber or ores) can they be leased or must they be bought? ___ ___

Have you attempted to forecast new sources? ___ ___

Are multiple supply areas available in case of short supply from one? ___ ___

18. RESIDENTIAL HOUSING

Are there enough rental properties for new employees? ___ ___

Are there plenty of houses available in the several cost brackets that will appeal to new salaried employees? ___ ___

Are there attractive suburbs within convenient distance of selected community? ___ ___

Are community housing starts keeping up with expected growth? ___ ___

As one index of community values, are residential property values increasing in line with area averages? ___ ___

Is over-all impression of residential areas an attractive one? ___ ___

Is community saddled with submarginal or slum areas? ___ ___

If so, are clearance and rehabilitation plans progressing? ___ ___

Does extent of home ownership among hourly type of employee indicate stability and community pride? ___ ___

19. EDUCATION

Are there sufficient schools, and adequately staffed? ___ ___

Is school building program in keeping with forecast community growth? ___ ___

What about vocational, trade, and apprentice training opportunities? Are they oriented toward your requirements? ___ ___

Do any institutions offer foremanship courses? ___ ___

Are college facilities near enough for offering special courses to key personnel? ___ ___

Are there adult education programs? Do they offer degrees? ___ ___

Is educational picture above average in terms of expense per pupil, teachers' salaries, PTA enthusiasm, building program, etc.? ___ ___

20. HEALTH AND WELFARE

Are there satisfactory medical and health services? ___ ___

Hospitals? General practitioners? ___ ___

How about auxiliary medical services (Dentists, visiting nurses, clinics, etc.) ___ ___

Do hospitals have adequate ratings by State Board of Health? ___ ___

How large an area is served by hospitals? ___ ___

Are Blue Cross and allied plans available? ___ ___

Does community have a workable disaster plan? __ __

Is there an adequate public health program? __ __

Is community welfare and relief load in reasonable proportion to that of area? __ __

Does community participate actively and responsibly in community fund program? __ __

Does the community have adequate and well-enforced sanitary laws? __ __

Are there reasonable state industrial and health laws? __ __

21. CULTURE AND RECREATION

Are there a variety of local outdoors attractions? (For example: golf, tennis, swimming, boating, fishing, hunting, skating, skiing.) __ __

What about family recreational areas? Parks and playgrounds? __ __

Is community near to good resort areas? __ __

Are there sufficient number of churches of varying denominations? __ __

Are there adequately staffed and equipped libraries? __ __

Are quality and variety of fraternal organizations attractive to potential newcomers? __ __

Do civic attractions operate, such as museums, theater, and musical functions? __ __

Are there a variety of paid amusements? __ __

What facilities are there for public gatherings, such as public buildings, auditoriums, gymnasiums, and church edifices? __ __

Is there an active press, including dailies, weeklies, radio and TV? __ __

22. GENERAL COMMUNITY ASPECTS

Is physical appearance of center of town a pleasant one? __ __

Are there good hotels, motels, restaurants? __ __

Are shopping and commercial districts well laid out for parking facilities and easy flow of traffic? ___ ___

To ease parking problems, are there fringe parking areas coupled with transit facilities? ___ ___

Are there adequate local banking facilities? ___ ___

23. COMMERCIAL SERVICES

Does community contain a diversified amount of commercial services required by industry? (Check and evaluate separately): ___ ___

- Major repair shops
- Electric motor maintenance
- Industrial distributors
- Lubricants
- Lumber and allied materials
- Engineering department supplies
- Stationery
- Food and sundry vending
- Local trucking
- Railway express
- Air freight services
- Postal service
- Blueprint service
- Industrial repair
- Air conditioning service
- Janitorial service
- Professional services
- Testing labs

Are adequate construction services and facilities available, either in the community or near it? (Check and evaluate separately): ___ ___

- Architects
- Engineers
- Prime contractors
- Subcontractors
- Mechanical
- Electrical
- Piping
- Carpenter
- Labor
- Rigger
- Special equipment
- Mason
- Plasterer
- Tile
- Painting
- Landscape
- Paving

Do specialized shops exist in or near the community which can help maintain your special equipment? ___ ___

24. SPECIFIC SITE CONSIDERATIONS

Is your product such that advertising value plays a big part in site selection as well as plant appearance? ___ ___

Has character of site been thoroughly explored? Typical factors: ___ ___

a. Topography.
b. Size of area available for purchase.
c. Layout and orientation
d. Drainage.

e. Freedom from flooding.
f. Any utilities already in place?
g. Subsoil, excavation, and foundation consideration
h. Gullies, streams, etc., to be bridged.
i. Any abnormal grading or landscaping problems?
j. Any pipelines or other utilities to be relocated?

Are general construction costs competitive with those of competing sites? __ __

Is site convenient for noon-hour shopping? __ __

If in limestone country any tell-tale sinkholes? __ __

Is site near enough an airport that CAA regulations must be considered in making building plans? __ __

Any restrictive covenants, easements, or other legal entanglements that would interfere with use of property? __ __

25. POLICE ASPECTS

Does police department have high standards of personnel, equipment, training, morale? __ __

Is police patrol service provided for industrial properties? __ __

Are there satisfactory policing arrangements outside city limits? __ __

Are private watchmen services or uniformed detective agencies available? __ __

Is incidence of crime as low as or lower than in surrounding area? __ __

Does community have a disproportionate number of bars and taverns? __ __

Is judiciary system well organized? __ __

26. FIRE ASPECTS

Does fire department have high standards of personnel equipment, training, morale? __ __

Is community fire insurance classifications up near the top? __ __

In case of serious fire, are adjacent communities near enough to send apparatus? __ __

Is site within fire hydrant limits? __ __

If so, are mains sized adequately? __ __

Are water pressure and reserve capacity sufficient for your needs? __ __

27. ROADS AND HIGHWAYS

Does quality of construction and maintenance indicate an efficient highway department? __ __

Does local highway system have adequate interconnections with national network? __ __

Are roads kept free of ice and snow? __ __

Is there a well-planned highway improvement program? __ __

Is proportion of unimproved roads steadily being reduced? __ __

28. TRASH AND GARBAGE

Is potential site within pickup limits? __ __

If not, are private contractors available? __ __

Does Board of Health exercise supervisory inspections over garbage collection methods? __ __

29. SEWAGE

Is site within sewage system limits? __ __

Can system handle your requirements? __ __

Does sewage department have realistic plans for expanding its network and equipment? __ __

30. PLANNING AND ZONING

Does community have an active and forward-looking city planning commission? __ __

Are smoke, noise, odors, etc. controlled? __ __

Have zoning sights been properly set in connection with new Federal Highway Program? __ __

Can you expect protection against undesirable neighbors? __ __

Have building codes been adapted to newer "permissive" basis? __ __

Do building inspectors have a reputation for honesty and integrity? __ __

31. STATE TAXES

What is existing gross debt of state, as a partial indication of future revenue needs? __ __

Is expected trend likely to keep in line with desired increased quality of services? __ __

Do state corporate taxes compare favorable with those of your competitors elsewhere? __ __

Does state have income taxes on individuals? __ __

If so, will they attract new employees from other states? Or keep them away? __ __

Does state levy property taxes? __ __

Is there a state sales tax? __ __

Does state grant permission to deduct Federal Income Tax? __ __

32. COMMUNITY FINANCIAL PICTURE

Does community indebtedness present a healthy picture? __ __

Is community tax picture well balanced between residential, industrial and commercial sources? __ __

Is pattern of community expenditures well balanced between needs and income? __ __

Is total community tax picture in line with services received? __ __

Do abnormally low community taxes indicate inferior schools, streets, other services? __ __

Are there sizable amounts of tax-free property which make an impact upon the community tax picture? __ __

Do future building plans of community government subdivisions threaten potential tax increases? __ __

Does community have special taxes? (Payroll, personal income, machinery, equipment, inventory sales, franchise, municipality, county, road improvements, sewer improvement, licences, permits, fees, etc.) ___ ___

Are community tax inducements offered to prospective industries? ___ ___

If so, is there evidence that high taxes later will wipe out initial tax advantage? ___ ___

Are residential tax rates reasonable? ___ ___

33. COMMUNITY BUSINESS CLIMATE

Is attitude of local officials sympathetic and enthusiastic towards existing and new industry? ___ ___

Is record of local government good as to honesty, efficiency, and principles? ___ ___

Does community have one or more good business-sponsored civic organizations devoted to improving business climate? ___ ___

If so, have tangible results been achieved? ___ ___

If more than one such organization, do they work together harmoniously? ___ ___

Have you checked reaction of local industries as to business climate? ___ ___

Have any manufacturers migrated from the community recently? ___ ___

Is it reasonable to expect normal industrial growth in the community? ___ ___

Are there existing or new industries in the community that help contribute to a stabilized economy? ___ ___

Is community well diversified industrially? ___ ___

Are community's industries dynamic and growing? ___ ___

Is size of community geared to your needs? (quantity and quality of industrial neighbors, labor pool, etc.) ___ ___

34. STATE BUSINESS CLIMATE

Are state legislative, executive, and judiciary branches performing as well as or better than counterparts in other states? ___ ___

Does state have a good reputation regarding attitudes towards industry? __ __

Are state salaries attractive enough to get and keep good people? __ __

Are state officials alert to improving its reputation towards industry? __ __

Are state wage and hours laws fairly written and administered? __ __

Is state workmen's compensation picture satisfactory? __ __

Is state unemployment compensation picture an equitable one? __ __

Does state have laws restricting the use of injunctions to prevent unreasonable union acts? __ __

Does the state have a law that prohibits secondary boycotts? __ __

Do state courts have a progressive viewpoint towards illegal strikes and picketing? __ __

Has history been satisfactory regarding state protection in law enforcement when required locally? __ __

Have you checked with other industries to determine presence of hidden restrictive state laws? __ __

Does state have an active and progressive development commission? __ __

35. COMMUNITY EMPLOYER EVALUATION

Have most employers demonstrated enlightened management policies? __ __

Do branch plants of the community represent national concerns with progressive management-labor-community policies? __ __

Have employers kept pace on a voluntary basis with rising wage standards? __ __

Do you rate the effective level of plant communication between employer and employee to be at least at a satisfactory standard? __ __

Will community progress along lines of guaranteed annual wage fit your proposed wage picture? __ __

Do employers willingly exchange data concerning labor contracts and wages?

Are industrial leaders (and business leaders in general) active in promoting a better business climate for the community and the state?

Do industrial leaders know and cooperate with local reporters, editors, and radio or TV commentators and program directors?

36. PHYSICAL CLIMATE

Has your general location survey thoroughly explored climatic conditions? Typical factors:

- a. General weather conditions.
- b. Elevation of community.
- c. Temperature ranges and averages.
- d. Average annual rainfall and snowfall.
- e. Humidity ranges and averages.
- f. Days with sunshine, rain, fog.
- g. Duration of killing frost.
- h. Low subsistence rates of South: clothing, heating, farming.
- i. Low maintenance costs of South-no frost (building and road maintenance) snow and ice removal.
- j. Velocity and direction of prevailing winds.
- k. Geographic extremes? For example: unusual or prolonged dry or wet conditions; cold, heat, hurricanes, floods, etc.
- l. Degree days per season.
- m. Effect of weather extremes on all forms of transportation? Rail, highway, air, water.

APPENDIX 2*

Selected Empirical Studies of Location Decisions

Investigator Year/Number of respondents	Formulation of the objective or question posed	Most significant factors and reasons mentioned
1. George Ellis	"Why did new establishments locate in New England?"	Personal reasons Market advantages Production relationships
1948/106	"Why did new establishments select specific communities in New England?"	Suitable building Labor supply Personal reasons
2. University of Michigan I	"How did your firm happen to locate this plant in Michigan rather than in some other State?"	Personal reasons To be near markets Availability of plants or sites
1950/188	Opinions on disadvantages of Michigan location	Wage rates and labor Pressure of organized labor Distance from materials
3. University of Michigan II	"Are there any minimum requirements which must be met for locating plants in this line of industry?"	Labor costs Proximity to markets Availability of labor Industrial climate
1961/239	"What were the main reasons for locating the plant in Michigan?"	Personal reasons Chance opportunity - site, etc. Proximity to customers
4. M.I. Logan 1963/72	Study of location and relocation decisions in the Sydney Area (Australia): main reasons for relocation of firms	Lack of space for immediate expansion High land values Move from rented premises Non-conforming to zoning Change in nature of operations

*Krumme, "Toward a Geography of Enterprise" Economic Geography, 45, 1969, pp 30 - 40

continued.

APPENDIX 2 (Continued)

Investigator Year/Number of respondents	Formulation of the objective or question posed	Most significant factors and reasons mentioned
5. McGraw Hill 1964/2000	"Which of the following considerations would be of importance in selecting the specific area or site?"	Trucking Reasonable cost of property Reasonable or low taxes Ample area for expansion
6. David Law 1964/28	Investigation of 28 firms which established plants in Northern Ireland:	
	(1) Reasons for movement of 19 British firms	Difficulty of obtaining labor Difficulty of expanding parent plant Board of Trade dispersal policy
	(2) Reasons for location in Northern Ireland of 27 firms	Availability of labor Factory available quickly Financial assistance
	(3) Locational disadvantages experienced by 28 firms	Transport costs Higher stocks Unreliable transport
7. J.S. Wabe 1965/91	Office decentralization in the London area:	
	(1) Reasons for considering decentralization	Expansion Integration of several offices Cost reduction Lease expiring
	(2) Reasons given for not decentralizing	Difficulty of retaining key staff Loss of business connections Disruptive effect of move Remain in central London for meetings

continued..

APPENDIX 2 (Continued)

Sources:

(1) George H. Ellis: Why New Manufacturing Establishments Located in New England: August, 1945, to June, 1948, <u>Monthly Review Federal Reserve Bank of Boston,</u> Vol. 31, April 1949, pp. 1-12

(2) G. Katona & J. Morgan: The Quantitative Study of Factors Determining Business Decisions, <u>Quart. Journ. of Econs.,</u> Vol. 66, Feb., 1952, pp. 67-90

(3) Eva Mueller and J. Morgan: Location Decisions of Manufacturers, <u>Amer. Econ. Rev. Papers and Proceedings</u>, Vol. 52, May, 1962, pp. 204-217

(4) M.I. Logan: Locational Behavior of Manufacturing Firms in Urban Areas, <u>Annals of AAG</u>, Vol. 56, No. 3, Sept. 1966, p. 463

(5) Cited by T.E. McMillan Jr.: Why Manufacturers Choose Plant Locations vs. Determinants of Plant Locations, <u>Land Econs.</u>, Vol. 43, August, 1965, pp. 241-243

(6) David Law: Industrial Movement and Locational Advantage, <u>Manchester School of Economic and Social Studies</u>, Vol. 32, May, 1964, pp. 131-154

(7) J.S. Wabe: Office Decentralization: An Empirical Study, <u>Urban Studies</u>, Vol. 13, February, 1966, pp. 35 - 55

APPENDIX 3

Sample Calculations

1) Standard Deviation for Materials, σ mat.

$$\sigma \text{ mat.} = \left[\frac{1}{m-1} \sum_{j=1}^{m} (f_j - \bar{f}_{mat.})^2 \right]^{1/2}$$

where σ mat. is the standard deviation for the materials factor
m is the number of locations
f_j is the cost of materials at location j, j=i,m
$\bar{f}_{mat.}$ is the average cost of materials over all locations

$$\bar{f} \text{ mat.} = 10^3 \times 10^{-1}(360 + 400 + 390 + 410 + 365 + 370 + 405 + 415 + 440 + 380)$$

= 394,000 (a factor of 10^3 will be dropped to simplify the arithmetic)

$$\sigma \text{ mat.} = \frac{1}{9}\left[\begin{array}{l} (360-394)^2 + (400-394)^2 + (390-394)^2 \\ + (410-394)^2 + (365-394)^2 + (370-394)^2 + (405-394)^2 \\ + (415-394)^2 + (440-394)^2 + (380-394)^2 \end{array} \right]^{1/2}$$

$$= \frac{5755}{9}^{1/2}$$

$$= 639.4^{1/2}$$

= 25.3 The factor of 10^3 is now applied and the standard deviation for materials over all ten locations is $25,300.

In the same way the standard deviations for all factors are computed to produce Table 3 on page 90.

2). Locational Factor Variance Ratio

$$\frac{\sigma i}{\sum\limits_{j=i}^{m} \sigma i_j}$$ defines the locational factor variance ratio

where σ_i is the standard deviation for factor i and $\sum\limits_{j=i}^{m} \sigma i_j$ is the sum of all the standard deviations for all factors i at all locations j.

For the materials factor,

$$\frac{\sigma \text{ max.}}{\sum\limits_{1}^{10} \sigma i_j} = \frac{25,300}{680,300}^{1} = 0.037$$

3) The exact weight to be assigned to any factor is determined by multiplying the expected annual cost equivalent for factor i at location j by the locational variance ratio for factor i. For example, to determine the weight to be assigned to the materials factor at location A, the expected annual cost equivalent for materials at location A, $360,000, is multiplied by the locational variance ratio for factor i, 0.037.

$$360,000 \times .037 = 13.3 \times 10^3$$

Again the factor of 10^3 is dropped to simplify the arithmetic. This does not affect the analysis because we are only interested in relative measures. In this way the bracket products in Table 4, page 92 are computed.

[1] Taken from Table 3, page 90.

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