OPTIMAL WAREHOUSE LOCATION MODEL

by

James Richard Gallagher

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Name: James Richard Gallagher Date of Degree: August, 1972

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Purpose of Study: The purpose of this research is to examine the warehousing system of Company X and to test different possible location sites. Through the use of simulation techniques, it was hoped to prove that 1) City-1, Ohio was the optimal location for a one-warehouse system; 2) Dallas, along with City-1 were the optimal location for a two-warehouse system; and 3) increase cost-savings might possibly warrant a three-warehouse system for Company X.

Findings and Conclusions: The results indicate that City-1, Ohio was the optimal location for a one-warehouse system; City-1, Ohio and Dallas, Texas were not the optimal two-warehouse combination; and that the increased cost-savings of a three-warehouse system does warrant further study and consideration.

ADVISER'S APPROVAL Robert B Breitenbach

OPTIMAL WAREHOUSE LOCATION MODEL

Report Approved:

Robert B Breitenbach

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Head, Department of Administrative Sciences

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CHAPTER I

INTRODUCTION

A physical distribution system can be conceptualized as several inventory storage points interconnected by a transportation network. Location of inventories or location of warehouse facilities, transportation service choices, and inventory-level alternatives are the three major decision areas that concern the physical distribution manager about the design of a distribution system. Once it is decided where the inventory storage points will be, the transportation service and inventory-level alternatives must be balanced to produce a maximum profit. Since location of warehouses, when treated independently of transportation and inventory levels, results in a loss of one degree of freedom in overall system design, an upper limit is established on the profits that the distribution system can generate.[1]

Warehouse location is not overly constraining to physical distribution system design when warehouses are initially well placed, and as long as demand and economic conditions remain relatively constant over time. However, if conditions change significantly and warehouse locations do not, the constraint of warehouse location may cause suboptimum profits; that is, there may be another warehouse location pattern that would yield higher profits.[2]

Regional warehouses may perform a variety of functions in distribution of a manufacturer's product. These include: 1) the reduction of transportation costs relative to direct shipment to customers by permitting bulk or quantity shipments from factory to warehouse; 2) the reduction of delivery costs by combining products manufactured at several factories into single shipments to individual customers; and 3) the improvement of customer relations by decreasing delivery time relative to direct factory shipment, thereby permitting customers to reduce their inventories. There are, however, substantial costs associated with the operation of a regional warehouse system.[3]

The location of a distributor's market is paramount in his choice of a warehouse site. Efficient customer servicing is a major cost factor--not directly in the form of shipping expenses, but indirectly in the need to retain the distributor's account.

Because warehouse labor is largely unskilled, with the exception of truck drivers, the problem of a good labor supply is not too pressing for many companies. However, warehousing does have its special requirements, and they call for an accent on youth; the nature of the business requires quick, strong men who are able to do a lot of stock moving in as short a time as possible.

The problem at issue may therefore be phrased as follows: determine the geographical pattern of warehouse locations which will be most profitable to the company by equating the marginal cost of warehouse operation with the transportation cost savings and incremental profits resulting from more rapid delivery.[4]

Judicious relocation of warehouses ensures maintaining a physical distribution system that can provide an optimum balance between revenue generated from the level of customer service maintained and the cost of providing this level of customer service. The decision problem is to determine the warehouse location plan so the cumulative profits from location and relocation are maximized for the entire period in which the warehouse is needed.[5]

Because a single location decision can be effective for twenty years or longer within which period a significant change in economic conditions may occur, the effect of the future time dimension cannot be neglected in location analysis.

Periodic updating of a location model solution and relocating of the warehouse can be a reasonable procedure when (a) demand and economic data can be predicted accurately for only a short time in the future and (b) the decision to relocate requires less lead time to implement than the time required for accurate forecasts. Since periodic updating has little sensitivity for reflecting future trends in the current decision, then any location must be justified by comparisons of current solutions to static location models alone. The author is saying that the periodic updating time period is too short to forecast accurately, and the company would have to rely on the basic model to justify warehouse locations. However, when accurate predictions can be made for longer periods, a more sophisticated analytical procedure is warranted. It is expected that a location plan anticipating when and where relocation will take place will yield overall profits for several reasons: 1) relocation of a warehousing operation may require a year or more between decision and implementation; 2) though periodic updating can potentially use current and, therefore, more accurate data, the decisions of when to consider relocating and of where to locate are arbitrary. For example, an arbitrary decision would be made on the number of years over which the fixed cost of relocating would be amortized since it is not known when the next relocation will occur.[6]

As most of the previous work in warehouse location has shown, the profitability of any one warehouse location during a time period is dependent on where other warehouses are located. Thus it is normally not possible to solve the location-relocation problem for each warehouse separately and generate a globally optimum solution. The problems must be solved together considering the interdependence of the profitability of the possible locations during each time period of the analysis.[7]

FOOTNOTES

[1]Richard H. Ballou, "Dynamic Warehouse Location Analysis," Journal of Marketing Research, August 1971, p. 530.

[2]Ibid.

[3]Alfred A. Kuehn and Michael J. Hamburger, "A Heuristic Program for Locating Warehouses," Management Science, July 1963, p. 523.

[4]Ibid.

[5]Ballou, p. 271.

[6]Ibid., p. 272.

[7]Leonard M. Lodish, "Computational Limitations of Dynamic Programming for Warehouse Location," Journal of Marketing Research, May 1970, p. 262.

CHAPTER II

DESCRIPTION OF MODELS

Five types of models have been examined in this literature search: dynamic programming; linear programming; heuristic programming; integer programming; and simulation. This paper will proceed with the warehouse location research project by discussing each of these models.

Dynamic Programming[1]

The best location plan is found by recasting the problem into a sequence of single-decision events. Then, according to Bellman's Principle of Optimality, in a sequence of decisions, whatever the initial decision, the remaining decisions must constitute an optimum policy for the state resulting from the initial decision. That is, once the first decision is made, the decision for the second event is based on the first decision, and the third decision is based on the second, etc., until all events have been evaluated.

The assumptions made in applying the dynamic programming technique to the location problem are in two classes: (1) assumptions about the input data and (2) those about the use of the technique. The input data is derived from solutions to a static location model. The particular model chosen--whether single or multiple facility, optimum-seeking or heuristic--affects the quality of the final dynamic location plan.

The dynamic location analysis discussed here is an extension of the popular static location analysis that provides both profit data and warehouse location alternatives for the dynamic analysis. The dynamic programming technique serves as the mathematical tool for finding a warehouse location-relocation plan that will yield maximum cumulative profits for a given planning period. Since the dynamic analysis gives location plans that anticipate when and where relocations will take place, the dynamic plan should provide a better basis for decision than periodic updating of the warehouse location as suggested by a static analysis alone.

The dynamic programming solution procedure requires determining optimal decisions for all possible states in period T, using these results to determine optimal decisions for all possible states in period T-1, etc. The number of separate decisions which must be determined is T x S. Each decision requires evaluating all possible warehouse configurations in the next period, S calculations. Thus the total number of calculations needed to obtain an optimal solution, C, is the number of decisions times the number of calculations per decision, or: $(C = T \times S^2)$.[2]

The only case in which dynamic programming would be computationally feasible for obtaining an optimal solution to a reasonable-sized problem is when each of the separate warehouse relocation problems could be considered as independent, ie., when the profitability of the location of each warehouse during the period is completely unrelated to the location of the other warehouses during the period. This is usually not the case in practice. Heuristic methods might be used to obtain good, but not necessarily optimal solutions.[3]

Whenever dynamic programming is raised as a possibility solution method for the warehouse location problem, it seems to connote certain problem definitions. That is, in the case of locating multiple warehouses within a single time period framework the problem is one of finding the best warehouse location arrangement under specific levels of demand, transportation costs, inventory costs, etc., to achieve some economic objective where all warehouses are economically interdependent. If the problem is extended to include multiple time periods, then optimal warehouse location patterns throughout the planning horizon also are a function of the economic interdependencies between location patterns from one time period to another. Because dynamic programming is not an effective solution technique when the relationship between stages is a complex one, the combinational difficulties quickly become insurmountable as increased numbers of warehouses for both of these problem statements are considered.[4]

Linear Programming[5]

Linear programming refers to a mathematical technique whereby an optimization problem dealing with the interaction of many variables and subject to specific constraints may be solved. The approach assumes that the most important relationships are linear, or approximately linear in nature.

The biggest advantage of the linear programming model lies in its ability to provide a framework for the systematic appraisal of many alternatives. A second advantage is the elementary mathematics that are required for solution.

Since the costs involved are to be linear, the question must be asked whether or not this limits the problems to which linear programming methods can be applied. The answer is a definite but qualified no! First, a great number of practical problems involve activities that are linear within the feasible range of the activities. Second, when the activities are not linear over their entire feasible range, it is very often possible to split the activity that is not linear into several activities, each of which is linear. Such a procedure can be used, for example, in handling the distribution method where there is a quantity discount on the rate. Thus, instead of having one activity that consists of shipping from a specific plant to a specific warehouse, we have two activities. The first is the activity of shipping any amount up to the amount at which the discount applies, and the second is the activity of shipping any amount to which the discount applies.

Therefore, the use of linear programming will at least insure the selection of the optimal strategy on the basis of the data that would be used by management anyway. When linear programming is to be applied in areas where cost data are not collected on a continuing basis, difficulties can arise in determining relevant costs. Here, linear programming can be used with each of a range of costs sets and the effect of changing alternatives can be noted. This in itself should provide management with a basis for decision.

A disadvantage to the linear programming method is summed up by the fact that the costs involved are not linear. This non-linearity can be best explained by examples of transportation and warehouse costs. To be linear, we have defined a transportation cost that must be twice as much for two units as for one. Actually the transportation costs would increase at a negative rate, due to discounts given for greater weights. Transportation costs increase, but not linearly. With each new warehouse in the distribution system, we incur additional costs.

A second disadvantage to the distribution method, perhaps more serious, is the aversion that most mathematical concepts meet when introduced. The feeling is really one of skepticism rather than antagonism. The question should be asked whether the outside consultant or the firm's personnel should be the one to implement the techniques.

A third disadvantage is that the carrier capability is not evaluated by the linear programming model. A transportation charge can be stated without regard to whether or not this rate, being the cheapest in terms of cost, is really the best in terms of service. Usually, the short-haul advantage would go to trucks, while the long-haul advantage lies with the rail shipment; however, these exceptions cannot be built into the model, but rather used as a modification on the model's final solution.

Heuristic Programming[6]

Heuristic programming is a good approach to use where the emphasis is on working towards optimum solution procedures rather than optimum solutions. This is not to say that we ever expect to obtain an optimum solution procedure. The requirement of optimality would, in fact, be contradictory to the concept of using heuristic techniques. Heuristic techniques are most often used when the goal is to solve a problem, so the solution is described in terms of accessibility characteristics rather than by optimizing rules. The traditional operations research approach has been to search for optimum solutions. The heuristic approach differs in the following ways: (1) explicit consideration is given to a number of factors (for example, computer storage capacity and solution time) in addition to the quality of the solution produced; (2) the evaluation of heuristics techniques is usually done by inductive rather than deductive procedures. That is, specific heuristics are justified not because they attain an analytically derived solution, but rather because experimentation has proved they are useful in practice.

The heuristic program that has been used for locating warehouses consists of two parts. The first is the main program, which locates warehouses one at a time until no additional warehouses can be added to the distribution network without increasing total costs. The second is the "Bump-and-Shift" routine, entered after processing in the main program is complete, which attempts to modify solutions arrived at in the main program by evaluating the profit implications of dropping individual warehouses or of shifting them from one location to another. The three principal heuristics used in the main program are: (1) most geographical locations are not promising sites for a regional warehouse (locations of promise will be at or near concentrations of demand); (2) near optimum warehousing systems can be developed by locating warehouses one at a time, adding at each stage of the analysis that warehouse which produces the greatest cost savings for the entire system; (3) only a small subset of all possible warehouse locations need to be evaluated in detail at each stage of the analysis to determine the next warehouse site to be added.

The "Bump-and-Shift" routine is designed to modify solutions reached in the main program in two ways. It first eliminates (bumps) any warehouse which is no longer economical because some of the customers originally assigned to it are now serviced by warehouses located subsequently. Then, to insure the servicing of each of the territories established from a single warehouse within each territory in the most economical manner, the program considers shifting each warehouse from its currently assigned location to the other potential sites within its territory.

The use of heuristics in solving these problems has two prime advantages relative to the currently available linear programming formulations and solution procedures; (1) computational simplicity, which results in substantial reduction in solution times and permits the treatment of large scale problems, and (2) flexibility with respect to the underlying cost functions, eliminating the need for restrictive assumptions. It also offers an important advantage relative to the simulation techniques in that it incorporates a systematic procedure designed to generate at least one near-optimal distribution system while providing approximately the same flexibility in the modeling of the problem.

Integer Programming[7]

The difficulty in integer programming is primarily caused by our inability to write down explicitly the constraints necessary for restricting the solutions to integer values only. In this section two main proposals on the solution of integer programming problems will be presented. They are the Method of Integer Forms developed by Gomory[8] and the alternative method proposed by Land and Doig.[9]

The Method of Integer Forms starts off by using the simplex to obtain an optimal continuous solution. If this solution is not an integer solution, then a new constraint is constructed according to a certain rule and incorporated into the problem, and the new problem is then reoptimized. This process is repeated until, due to the nature of the new constraints added to the system, an optimal solution is found which is also an integer solution. We now have the optimal integer solution to the original problem. In the alternative approach of Land and Doig also, an optimal continuous solution is obtained first by the simplex method. If it is not an integer solution, one of the discrete variables is then chosen arbitrarily to be first integerized. This is accomplished by using "parametric programming" to determine the range of feasible values of this variable and noting the integer values within this range together with the corresponding values of the objective function. Next we fix this variable at the most desirable integer value in terms of the value of the objective function determined above, and proceed to find the range of feasible integer values of a second variable. We repeat this for the next best integer value of the first variable. From these two ranges of feasible integer values of the second variable, select particular integer values, which together with the predetermined integer values of the first variable, yield the higher values of the objective function. These combinations of integer values of the first two variables then provide the basis for integerizing a third variable, a fourth variable, and so on until all variables required to be integers are integerized. At every step the direction of further investigation is guided by reference to the value of the objective function yielded by partially integerized solutions obtained so far. In the end it is easy to find the best solution among the several fully integerized alternatives available. This then is the optimal integer solution to the problem.

From the brief descriptions of the two methods above, it should be clear that Gomory relies on reshaping the problem to force out the proper solution, whereas Land and Doig engage in a direct and systematic search for the optimum. The latter approach requires extensive and careful record-keeping in order to test exhaustively all integer solutions that are likely to develop into the optimal solution. Consequently, it would seem to be the more laborious of the two. On the other hand, since the Gomory method does not at any point require that any particular variable remain an integer, it is at present only applicable to problems where all variables are required to assume integer values.

Simulation[10]

Simulation provides the ability to operate some particular phase of a business on paper--or in a computer--for a period of time, and by this means to test various alternative strategies and systems. It takes into account each of the important factors involved in the operation of a distribution system: transportation rate structures, warehouse operating costs, the characteristics of customers' demand for products, costs of labor and construction, factory locations, product mix and production capacities, and all other significant elements.

Since the simulation represents the essential parts of the actual distribution system, it permits the operation of the system in such a way that a whole year's transactions can be run through under close scrutiny. Goods flow through the system, from factory to mixing point, to warehouse, to the customer; and transportation and operating costs are incurred just as they would be in real life.

A distribution system exists in order to link production activity and consumption activity. A company interested in studying its warehouse location problem could start by specifying where production takes place and where the majority of its customers are located. It could, initially assume arbitrary locations of warehouses. If proper cost information, consumption information, and production information are available, then the costs of distribution associated with a given assumed configuration of warehouses could be determined. These results could be compared with costs accruing under other assumed configurations.

Between two basic factors: (1) customer location and needs, and (2) factory location and production characteristics, lies the distribution system. Specifically, these are the factors that had to be taken into account in setting up the model:

1) How frequently customers order, how much they order, what they order, where they are located, and how they prefer to take receipt of the ordered goods.

2) The kinds of goods that can be supplied from any given factory point, the quantities that can be supplied, and the location of the factories.

3) The relationship between shipping rates and points of origin and destination, for truck and rail transportation, and for different types and size of orders.

4) The relationship between total handling costs and total volume handled at warehouses and mixing points.

5) The knowledge of where these relationships differ, so that adjustments to cost and volume estimates might be made.

In concept the program for the simulation described is quite simple. Stored on tape is all the information relating to transportation, handling, and delivery costs, geographic adjustment factors, factory locations, and the factory production specifications. Even the program itself is stored on tape.

The basic process is to vary warehouse configurations and to observe and compare the resultant effects on distribution costs. To do this we must compute in detail the annual costs for operating the proposed distribution system for a year. Included are such costs as those for each of the warehouses and mixing points, for all shipments (both from factories to warehouses and warehouses to customers), and for each of the several thousand customers, or for a sample from these costs.

Now the simulation is ready to accomplish its twofold objective: 1) to enable management to close in rapidly on the number and approximate locations of warehouses which will achieve lower costs of distribution, and 2) to discover where changes can be made in warehouse locations which will lower costs still further.

FOOTNOTES

[1]Richard H. Ballou, "Dynamic Warehouse Location Analysis," Journal of Marketing Research, August 1971, pp. 523-545.

[2]Leonard M. Lodish, "Computational Limitations of Dynamic Programming for Warehouse Location," Journal of Marketing Research, May 1970, p. 262.

[3]Ibid., p. 263.

[4]Ronald H. Ballou, "Computational Limitations of Dynamic Programming for Warehouse Location: A Comment," Journal of Marketing Research, May 1970, p. 263.

[5]Tom Adams, "Use of Linear Programming in the Selection of Optimal Shipping Points," Transportation Journal, Spring 1969, pp. 11-20.

[6]Alfred A. Kuehn and Michael J. Hamburger, "A Heuristic Program for Locating Warehouses," Management Science, July 1963, pp. 523-545.

[7]An-min Chung, Linear Programming (Columbus, Ohio: Charles E. Merrill Books, Inc., 1963), pp. 300-311.

[8]R. E. Gomory, "Outline of an Algorithm for Integer Solutions to Linear Programs," Bulletin of American Mathematical Society, 1958, pp. 275-278.

[9]A. H. Land and A. G. Doig, "An Automatic Method of Solving Discrete Programming Problems," Econometrica, 1960, pp. 497-521.

[10]Harvey N. Shycon and Richard B. Maffei, "Simulation--Tool for Better Distribution," Harvard Business Review, November 1960, pp. 65-75.

CHAPTER III

OPTIMAL WAREHOUSE LOCATION MODEL

In the previous section five types of models were described that could be used for optimal warehouse location analysis. Since the purpose of this paper was to develop a realistic model in which the number of assumptions that would have to be made would be held to a minimum, the use of the simulation model was employed. All manipulations of the model will be based on a decision process which was designed for this project.

Company X, which has just undergone the process of selecting a new warehouse site, has been chosen to exemplify the use of this model. Company X now has two warehouses, one in City-1 located in Ohio and one in Dallas, Texas. This study will use their demand figures and an improvised version of their freight rates. The purpose of this study is to see if: (1) they located the new warehouse in the optimal place based on transportation costs, manufacturing costs, and warehousing costs, and (2) if two is the optimal number of warehouses.

The company had freight rates from each of four possible warehouse locations (Dallas, Texas; Atlanta, Georgia; City-1, Ohio; and Memphis, Tennessee) to their forty-nine points of destinations; however, in the listing of their destination points, they just gave the state and not the city. By a random process, this study selected four additional locations for warehouse sittings which are to be added to the four that Company X has selected. The four locations which were selected to be used in this study were: Ely, Nevada; Spokane, Washington; Prescott, Arizona; and Pierre, South Dakota. The four locations selected by Company X are located along the East Coast and south-central areas of the United States; thus, this project's selections are located along the West Coast and the north-central parts of the United States. From its vast geographical coverage, this study should reveal the optimal locations for one, two, and three warehousing systems. As far as warehousing costs are concerned we will assume that we are speaking in terms of public warehousing and that the rental costs are the same at all eight locations. This project proceeded to apply some logical mileage distance to each freight rate given, and then tried to establish, logically, a city that was in the named state, about that mileage distance from the particular warehouse.

Company X had in its study the per-hundred-weight costs to the various destination points; however, these destination points were stated in terms of state only. This project, therefore, selected one town in each state as a destination point. The selection of each town was based on three sources: 1) the per-hundred-weight rate to each state; 2) a mileage hierarchy based on per-hundred-weight rates; and 3) the mileage distance from warehouse point to destination, to the nearest hundred miles.

An example of this would be that Company X had listed that the cost from Dallas, Texas to the state of Arkansas was $2.64 per-hundred-weight. A logical distance for this per-hundred-weight rate, based on Company X's study, is three hundred miles, and a logical town in Arkansas that is this distance from Dallas is Pine Bluff. The average per-hundred-weight rates can be found in Table I, page 34.

There are three manufacturing plants and they are located in the cities of: Aberdeen, Mississippi; Stillwater, Oklahoma; and City-2, Ohio. The production capacity of these is as follows: Mississippi--20% of the total production, Oklahoma--20% of the total production, and Ohio--60% of the total production. The inbound freight rate was computed on a basis much the same as that of the outbound freight rates. Company X had listed an inbound freight rate to each of the four potential warehouses from each of the three manufacturing plants. In this research project the mileage was estimated to the nearest hundred miles with the help of a compass and a world atlas. Next the given rates were applied to the four original sites and then projected for the additional four sites, again based on the same procedure as before. Company X also had in their study the per-hundred-weight rate to the various warehouses, from the production plants. Both production plants and warehouses were stated in terms of towns; thus the distance from the production plant town to the warehouse towns was marked off with the aid of a compass, and the corresponding rates were applied. An example of this would be a production plant located in Aberdeen, Mississippi, shipping to a warehouse located in Dallas, Texas. The distance involved is about four hundred miles and the per-hundred-weight cost recognized by Company X is $1.41. Using the above logic, the rates were adjusted accordingly, based upon the location from which they were shipped. Company X estimated that it costs about 10¢ per pound to manufacture their product. Using this estimate and two Employment and Earnings books, this 10¢ per pound cost was projected to each manufacturing site. In doing so, Oklahoma was selected as the norm as far as labor is concerned. These projections can be seen in Table II, page 35.

Inbound transportation costs must be given consideration in determining the location for a Regional Distribution Center. On the other hand, these should not be the major determining factors since the freight will move out the three plant locations by rail at bulk rates. As a result, serious consideration of Company X's outbound LTL (truck) rates must take precedence.

In the computer part of this research project, to keep everything logical and simplified, there were three different programs: one for a one-warehouse system, one for a two-warehouse system, and one for a three-warehouse system. In each system the data-card decks will have to be submitted manually. This could be a weakness of this model, but in trying to keep it simplified so its use would be available to all, this was considered to be justifiable and necessary.

In this model the assumption has been made that the limit for the maximum number of warehouses be arbitrarily set at three. Since this model pertains to the concept of public warehousing, it only makes sense that the more warehouses that are established at the same cost, the more money that will be saved. It is necessary to make this assumption, because at some point, there will be so many warehouses that the carload savings on inbound freight will be lost and the truckload savings on outbound freight will also be lost.

On the data cards in the first three columns the per-hundred-weight rate from each warehouse to each of the forty-nine destinations is punched. The next five columns were reserved for the demand at each destination point stated in hundreds of pounds. The destination point number (1-49) is punched in the next two spaces, and finally column 11 is reserved for the warehouse number which was serving that particular area.

In the program for one-warehouse (refer to Table VII, page 40) the computer is told to read each data card, multiply the per-hundred-weight rate times the demand recorded in hundreds of pounds, and then to write the product and the number of the destination point. Next the computer adds each of the products to the variable SUM, which started out as zero. Then the computer is instructed to see if that was the last card (IF (I.GT.49) GO TO 25). If it was the last data card the computer will then write the final value of SUM, which is the total outbound transportation cost for this one warehouse serving all of the forty-nine points; however, if not, the computer will go back and read the next data card and perform all of the above operations again, until it reaches the last card. The computer will do this for each of the eight possible warehouse locations.

In the program for two warehouses (refer to Table VIII, page 41) the computer is told to read each data card for Warehouse X, multiply the per-hundred-weight rate times the demand recorded in hundreds of pounds, and then to store it in the array X(I). Then the computer checks to see if that was the last data card of X(I) by the following method, (I = I + 1; IF (I.GT.49) GO TO 20). If it was not, the computer will go back and read the next data card and perform the same operations as before until (I.GT.49). If it was the last data card, the computer will start reading the data cards for Warehouse Y, multiplying the per-hundred-weight rate times the demand recorded in hundreds of pounds, and then to store it in the array Y(I). Then the computer will check and see if that was the last data card of Warehouse Y. If not, the computer will go back and read another card and perform the same operations as before until (I.GT.49). If it was the last data card of Warehouse Y the computer will start comparing the cost at each destination point from each warehouse and add the cheaper one to sum, (IF (X(I).GT.Y(I)) GO TO 35). Then the computer will continue to compare Warehouse X and Warehouse Y and will write the cheaper cost for each destination point, the destination point number, and the number of the warehouse which can serve that point cheaper. At this point the computer will check to see if that was the last destination point comparison; if it was not, the computer will return to the point where it compares the destination points served by each warehouse and continues comparing until (I.GT.49). If it was the last destination-point comparison, the computer will print each warehouse number and the total cost involved, using these as an outbound distribution system.

In the program for three warehouses (refer to Table IX, page 42) the computer performs the same operations for Warehouses X, Y, and Z. It reads each data card, multiplies the per-hundred-weight rate times the demand in hundreds of pounds, and then stores the product in its own array: X(I), Y(I), or Z(I). Then the computer checks to see if it has read the data cards for all forty-nine locations. If not, it will read another card and perform the above operations. If the computer has read all the data cards of three warehouses serving forty-nine locations then it is ready to compare the costs from all three warehouses to each of the forty-nine locations, and to write out the cheapest cost, the destination point number, and the number of the warehouse which supplied the cheapest cost. If the computer has not compared all forty-nine locations, it is to return to the next destination point and compare the cost from all three warehouses and to write out the cheapest cost, the destination point number, and the number of the warehouse which supplied the cheapest cost. If the computer has compared the warehousing costs of outbound transportation at all forty-nine destination points, then it is to write out the number of each of the warehouses and the total outbound transportation system cost using those three warehouses.

Outbound transportation costs are the chief consideration in a transportation system's total cost, because inbound transportation is usually able to take advantage of the bulk rates by rail. Because the major emphasis is placed upon outbound transportation costs, we will compute manufacturing and inbound transportation costs only for the optimal configuration in each system. These results may be seen in Table III, page 36.

CHAPTER IV

RESULTS

In comparing each of the eight possible locations for a one-warehouse system we find that City-1, Ohio, is our optimal location, just using outbound transportation cost comparisons. The total cost for Ohio was $2,017,116. The next two closest locations, cost-wise, were Tennessee, at $2,174,387 and Georgia, at $2,263,656. As it turns out, Ohio is where Company X is from and it is where they located their first warehouse; thus for a one-warehouse system, Company X seemed to have picked the optimal or near-optimal warehouse location as far as outbound transportation is concerned.

In comparing each of the twenty-eight possible locations for a two-warehouse system we find that Nevada and South Dakota are the optimal locations, having a total cost of $1,608,367. The next four closest locations, cost-wise, were Arizona and Ohio at $1,666,233; Washington and Ohio at $1,722,433; Texas and Ohio at $1,734,358; and Ohio and Tennessee at $1,752,875. As this turns out, Company X chose Ohio and Texas as the two-warehouse system, and according to outbound transportation costs this system is about $126,000 more expensive than the optimal solution designated by this program. It must be realized that the warehouse in Ohio has many fixed costs involved, but the second alternative using Ohio for a warehouse location is $52,000 cheaper than the one Company X is using (see Table V, page 38).

In comparing each of the fifty-six possible locations for a three-warehouse system we find that Nevada, Ohio, and Tennessee are our optimal locations, with a total outbound transportation cost of $1,429,485. The next four closest locations, cost-wise, were: Nevada, Texas, and Ohio at $1,458,359; Nevada, Ohio, and Georgia at $1,475,724; Arizona, Ohio, and Tennessee at $1,502,907; and Arizona, Texas, and Ohio at $1,532,604.

In figuring the inbound transportation and manufacturing costs for our three optimal systems, refer to Table III, page 36. The total production and inbound transportation costs for a one-warehouse system (City-1, Ohio) were $5,459,854.

The total production and inbound transportation costs for a two-warehouse system (Ely, Nevada and City-1, Ohio) were $5,510,002.

The total production and inbound transportation costs for a three-warehouse system (Ely, Nevada; Memphis, Tennessee; and City-1, Ohio) were $5,497,688.

By defining optimal warehouse system costs as consisting of transportation-in, production, and transportation-out, a total system's cost for each of the three systems can be computed. They are:

one-warehouse system = 5,459,854 + 2,017,116 = $7,476,970

two-warehouse system = 1,608,367 + 5,510,002 = $7,118,369

three-warehouse system = 1,429,485 + 5,497,688 = $6,927,173

CHAPTER V

RECOMMENDATIONS

Based on the research compiled in this project, it should be recommended to Company X that when production increases they should expand their production capacities at Aberdeen, Mississippi and at Stillwater, Oklahoma. Both plants have much cheaper labor costs than City-2, Ohio, and this reduction in labor costs would significantly lower Company X's production costs (see Table II, page 35).

Company X should also investigate the possibility of establishing a third warehouse in their transportation system, for it would lower their outbound transportation cost by approximately one hundred and seventy thousand dollars (see Table V, page 38 and Table VI, page 39).

It was interesting to take note of the patterns of recurrence that takes place in the two-warehouse system. For instance, Texas only appears twice in the top fifteen out of twenty-eight warehouse combinations in the two-warehouse systems. It should be recommended to Company X that they should re-examine their data and see if Dallas, Texas really is the optimal location for their second warehouse. The first time Texas appears in the two-warehouse system is after three other combinations, all considerably cheaper. (See Table V, page 38.)

A final area in which some changes could be made would be that of the computer program itself. This project had small arrays set up for the three different systems. If one big array was set up and all the data cards run through at once, an enormous amount of time could be saved. So much efficiency was lost, as far as time is concerned, by the way this project was set up; however, the reasoning for this was that one would not have to be a computer programmer to understand it.

Future Research

As with any study, there is always room for future research. Any number of warehouses could be chosen to supplement or substitute the existing three used in this project. With the substitution or addition of different warehouse locations, the results could be altered. Major differences could be found in the results of a similar study if additional or different variables were introduced. The variables used in this study were believed to be good indicators of the differences in transportation costs (both inbound and outbound) and production costs. However, there is ample room for improvement in the area of the assumptions that were made in this study: type of warehousing used; more concrete freight rates and production costs; and several others. There is a definite need for more realistic data.

TABLE I

AVERAGE RATE/CWT

Miles	Rate/CWT
100	1.83
200	2.25
300	2.64
400	2.91
500	3.19
600	3.61
700	3.84
800	3.94
900	4.47
1000	5.45
1100	5.65
1200	5.99
1300	6.21
1400	6.23
1500	6.48
1600	6.95
1700	7.06
1800	7.21
1900	7.49
2000	7.64
2100	7.89
2200	8.09
2300	8.30
2400	9.13
2500	9.13

TABLE II

PRODUCTION COSTS/CWT + INBOUND TRANSPORTATION

From	To							
Aberdeen, Miss.	Ohio	Ariz.	Wash.	S.Dak.	Texas	Nevada	Tenn.	Georgia
Miles	1200	1400	2400	1200	500	2000	200	400
Cwt cost	1.93	2.00	2.45	1.93	1.41	2.40	.90	1.27
Production costs	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50
Total costs/cwt	9.43	9.50	9.95	9.43	8.91	9.90	8.40	8.77
Stillwater, Okla.	Ohio	Ariz.	Wash.	S.Dak.	Texas	Nevada	Tenn.	Georgia
Miles	1200	900	1800	800	300	1300	500	900
Cwt	1.93	9.87	2.75	1.75	.99	2.50	1.29	1.87
Production costs/cwt	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Total cwt costs	11.93	11.87	12.75	11.75	10.99	12.50	11.29	11.87
Shelby, Ohio	Ohio	Ariz.	Wash.	S.Dak.	Texas	Nevada	Tenn.	Georgia
Miles		2100	2200	900	1000	2000	700	700
Cwt	-	3.74	3.92	1.95	2.00	3.56	1.79	1.79
Production costs/cwt	12.50	12.50	12.50	12.50	12.50	12.50	12.50	12.50
Total cost/cwt	12.50	16.24	16.42	14.45	14.50	16.06	14.29	14.29

TABLE III

INBOUND AND PRODUCTION COSTS OF OPTIMAL SYSTEMS

I Warehouse System

Warehouse #6 City-1, Ohio

Plant	City-2 Ohio	27,828,000 lbs.	x 12.50 cwt	=	3,478,500
Plant	Stillwater, Okla.	9,276,000 lbs.	x 11.93 cwt	=	1,106,627
Plant	Aberdeen, Miss.	9,276,000 lbs.	x 9.43 cwt	=	874,727
					$5,459,854

II Warehouse System

Warehouse #2 Ely, Nevada

Plant	Oklahoma	8,798,000 lbs.	x 12.50	1,099,750

Warehouse #6 City-1, Ohio

Plant	Oklahoma	478,000 lbs.	x 11.93	57,025
Plant	Mississippi	9,276,000 lbs.	x 9.43	874,727
Plant	Ohio	27,828,000 lbs.	x 12.50	3,478,500
				$5,510,002

III Warehouse System

Warehouse #2 Ely, Nevada

Plant	Oklahoma	8,798,000 lbs.	x 12.50	1,099,750

Warehouse #7 Memphis, Tennessee

Plant	Oklahoma	478,000 lbs.	x 11.29	53,966
Plant	Mississippi	9,276,000 lbs.	x 8.40	779,184
Plant	Ohio	4,820,000 lbs.	x 14.29	688,788

Warehouse #6 City-1, Ohio

Plant	Ohio	23,008,000 lbs.	x 12.50	2,876,000
				$5,497,688

TABLE IV

OUTBOUND TOTALS FOR A ONE-WAREHOUSE SYSTEM

	One-Warehouse	Total Outbound Cost
VI	City-1, Ohio	$2,017,116
VII	Memphis, Tennessee	$2,174,387
VIII	Atlanta, Georgia	$2,263,656
IV	Dallas, Texas	$2,519,631
V	Pierre, South Dakota	$2,656,597
II	Ely, Nevada	$3,238,488
III	Prescott, Arizona	$3,252,451
I	Spokane, Washington	$3,492,506

TABLE V

OUTBOUND TOTALS FOR A TWO-WAREHOUSE SYSTEM

	Two-Warehouse	Total Outbound Cost
II & VI	Ely, Nevada Pierre, South Dakota	$1,608,367
III & VI	Prescott, Arizona City-1, Ohio	$1,666,233
I & VI	Spokane, Washington City-1, Ohio	$1,722,433
IV & VI	Dallas, Texas City-1, Ohio	$1,734,358
VI & VII	City-1, Ohio Memphis, Tennessee	$1,752,875
V & VI	Pierre, South Dakota City-1, Ohio	$1,765,048
II & VIII	Ely, Nevada Atlanta, Georgia	$1,836,686
II & VII	Ely, Nevada Memphis, Tennessee	$1,843,530
VI & VIII	City-1, Ohio Atlanta, Georgia	$1,884,091
III & VII	Prescott, Arizona Memphis, Tennessee	$1,902,430
III & VIII	Prescott, Arizona Atlanta, Georgia	$1,914,082
I & VII	Spokane, Washington Memphis, Tennessee	$1,955,311
I & VIII	Spokane, Washington Atlanta, Georgia	$1,956,300
V & VIII	Pierre, South Dakota Atlanta, Georgia	$1,965,215
IV & VIII	Dallas, Texas Atlanta, Georgia	$1,995,529

TABLE VI

OUTBOUND TOTALS FOR A THREE-WAREHOUSE SYSTEM

	Three-Warehouse	Total Outbound Cost
II,VI,VII	Nevada, Ohio, Tennessee	$1,429,485
II,IV,VI	Nevada, Texas, Ohio	$1,458,359
II,VI,VIII	Nevada, Ohio, Georgia	$1,475,724
III,VI,VII	Arizona, Ohio, Tennessee	$1,502,907
III,IV,VI	Arizona, Texas, Ohio	$1,532,604
II,V,VI	Nevada, South Dakota, Ohio	$1,540,674
I,VI,VII	Washington, Ohio, Tennessee	$1,541,266
III,VI,VIII	Arizona, Ohio, Georgia	$1,549,145
I,IV,VI	Washington, Texas, Ohio	$1,557,732
I,II,VI	Washington, Nevada, Ohio	$1,565,302
II,III,VI	Nevada, Arizona, Ohio	$1,589,588
I,VI,VIII	Washington, Ohio, Georgia	$1,589,788
III,V,VI	Arizona, South Dakota, Ohio	$1,607,059
V,VI,VII	S. Dakota, Ohio, Tennessee	$1,607,265
IV,V,VI	Texas, South Dakota, Ohio	$1,643,159

TABLE VII

COMPUTER PROGRAM FOR A ONE-WAREHOUSE SYSTEM

```
   I = 1
   SUM = 0.0
 1 FORMAT (F3.2, F5.0, I2, I1)
10 READ (5,1) X, Y, N, IW
   Z = Y * Y
   WRITE (6,5) Z,N
   SUM = SUM + Z
   I = I + 1
   IF (I.GT.49) GO TO 25
   GO TO 10
25 WRITE (6,3) SUM, N, IW
 3 FORMAT (F9.0, 1X, I2, I1)
 5 FORMAT (1X, F9.0, 1X, 'POINT NUMBER', 1X, I2)
   STOP
   END
```

TABLE VIII

COMPUTER PROGRAM FOR A TWO-WAREHOUSE SYSTEM

```
   DIMENSION X(50), Y(50)
   I = 1
   SUM = 0.0
10 READ (5,1) A, B, K, IW1)
 1 FORMAT (F3.2, F5.0, I2, I1)
   TOT = A * B
   X(I) = TOT
   I = I + 1
   IF (I.GT.49) GO TO 20
   GO TO 10
20 I = 1
25 READ (5,1) A, B, N, IW2
   TOT = A * B
   Y(I) = TOT
   I = I + 1
   IF (I.GT.49) GO TO 30
   GO TO 25
30 I = 1
39 IF (X(I).GT.Y(I)) GO TO 35
   SUM = SUM + X(I)
   WRITE (6,5) X(I), I, IW1
   I = I + 1
   IF (I.GT.49) GO TO 50
   GO TO 39
35 SUM = SUM + Y(I)
   WRITE (6,5) Y(I), I, IW2
   I = I + 1
   IF (I.GT.49) GO TO 50
   GO TO 39
50 WRITE (6,2) IW1, IW2, SUM
 2 FORMAT (1X, 'TOTAL COST USING WAREHOUSES' 1X, I2, 1X,
  1'AND', 2X, I2, 2X, 'IS', 1X, F9.0)
 5 FORMAT (1X, F9.0, 1X, 'POINT NUMBER', 1X, I2, 1X,
  2'WAREHOUSE NUMBER', 1X, I1)
   STOP
   END
```

TABLE IX

COMPUTER PROGRAM FOR A THREE-WAREHOUSE SYSTEM

```
   DIMENSION X(50), Y(50), Z(50)
   I = 1
   SUM = 0
10 READ (5,1) A, B, K, IW1
 1 FORMAT (F3.2, F5.0, I2, I1)
   TOT = A * B
   X(I) = TOT
   I = I + 1
   IF (I.GT.49) GO TO 20
   GO TO 10
20 I = 1
25 READ (5,1) A, B, N, IW2
   TOT = A * B
   Y(I) = TOT
   I = I + 1
   IF (I.GT.49) GO TO 30
   GO TO 25
30 I = 1
40 READ (5,1) A, B, I, IW3
   TOT = A * B
   Z(I) = TOT
   I = I + 1
   IF (I.GT.49) GO TO 60
   GO TO 40
60 I = 1
39 IF (X(I).GT.Y(I)) GO TO 35
   IF (X(I).GT.Z(I)) GO TO 65
   SUM = SUM + X(I)
   WRITE (6,5) X(I), I, IW1
   I = I + 1
   IF (I.GT.49) GO TO 100
   GO TO 39
35 IF (Y(I).GT.Z(I)) GO TO 65
   SUM = SUM + Y(I)
   WRITE (6,5) Y(I), I, IW2
   I = I + 1
   IF (I.GT.49) GO TO 100
   GO TO 39
65 SUM = SUM + Z(I)
   WRITE (6,5) Z(I), I, IW3
   I = I + 1
   IF (I.GT.49) GO TO 100
   GO TO 39
```

TABLE IX (Continued)

```
100 WRITE (6,2) IW1, IW2, IW3, SUM
  2 FORMAT (1X, 'TOTAL COST USING WAREHOUSES' 1X, I2,','
   11X, I2, 1X, 'AND', 1X, I2, 1X, 'IS', 1X, F9.0)
  5 FORMAT (1X, F9.0, 1X, 'POINT NUMBER', 1X, I2, 1X,
   2'WAREHOUSE NUMBER', 1X, I1)
    STOP
    END
```

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VITA

James Richard Gallagher

Candidate for the Degree of

Master of Business Administration

Thesis: OPTIMAL WAREHOUSE LOCATION MODEL

Major Field: Business Administration

Biographical:

Personal Data:

Born in Tulsa, Oklahoma, July 9, 1947, the son of Mr. and Mrs. Joesph Robert Gallagher.

Education:

Graduated from College High School, Bartlesville, Oklahoma, in May, 1965; received a Bachelor of Science degree from Oklahoma State University in 1971, with a major in Marketing; completed requirements for the Master of Business Administration degree at Oklahoma State University in August, 1972.