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MODELING THE MOTOR CARRIER TERMINAL SITE SELECTION DECISION:
A STUDY OF THE ECONOMIC FEASIBILITY OF URBAN
CONSOLIDATION TERMINAL LOCATIONS

DISSertation

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

Andrew Wen-Yuh Lai, B.A., M.A.

****

The Ohio State University
1974

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CHAPTER I

INTRODUCTION

Transportation and city planners have in recent years given serious attention to the development of comprehensive transportation plans for the movement of people in urban areas. The integration of commodity flow into these transportation plans has unfortunately been neglected to a large degree.

One form of commodity flow which has drawn much recent attention is intraregional goods shipment. Intraregional shipment is defined here as shipment having both source and destination within a certain area, such as the central business district (CBD) of an urban center.

There are several reasons for the interest in the intraregional shipping problem. First, the volume of intraregional shipment has increased substantially in the last few decades and is expected to continue its rapid growth for the foreseeable future. The Tri-State study, involving New York, New Jersey, and Connecticut, showed that during the period 1945-1965 internal freight shipments increased by 143 percent, while population increased by only 31 percent. During the period 1965-1985 it is estimated that internal freight
shipments will increase by 66 percent, while population will increase by only 26 percent (Wood, 1970). On a larger scale, McDonnell, et al. (McDonnell, Chappel, and Smith, 1971) estimate the rate of growth for internal freight shipments in thirteen major United States cities to be 3.6 percent per year during the interval 1955-1990.

The rate of growth in the number of shipments is also reflected in shipping costs. For example, the total cost of moving goods within the nation's urban areas has increased from $14.3 billion to $50.5 billion, or from 2.80 percent to 3.65 percent of the GNP from 1960 to 1972. The year 1970 marked the first time in which intraurban distribution costs exceeded intercity costs (Wood, 1974).

A second reason for interest in the intraregional shipping problem is that the costs of intraurban shipments, particularly small shipments, are unnecessarily excessive, owing to inadequacies in the present shipping system. One national carrier conducted an extensive study of shipments under 300 pounds in 1967, and concluded that there was an average loss of $4.92 for each small shipment. McDermott has observed that the deficiencies of intraurban goods

\[1\] The increase in the cost of intraurban distribution may be partially caused by the increase in the size of urban regions in recent years.

\[2\] In order to protect its proprietary interests, this regular route common carrier prefers not to be identified.
movement are offsetting the improvement in productivity of intercity motor carrier shipping (1973, p. 2).

The main source of low productivity in intraurban shipments in the CBD is street congestion. Virtually all intraregional shipments are served by private and public (for-hire) motor carriers (Wood, 1970, p. 97). It is estimated that between 62 percent and 75 percent of this freight is moved by private carriers with the remainder being handled by public carriers (McDermott, 1973, p. 49; Wood and Leighton, 1969, p. 330; Smith, 1969). Thirty-seven percent of all these commercial vehicle trips have either their origin or destination in the CBD, an area which represents only about four percent of an urban region's land area (Smith, 1969, p. 68). Furthermore, trucks in the CBD are generally in transit between 9:00 A. M. and 11:00 A. M. and between 4:00 P. M. and 6:00 P. M. Loading and unloading of trucks usually takes place between 11:00 A. M. and 4:00 P. M. (Smith, 1969, p. 16). Due to the resultant congestion, it is not uncommon for a driver to average as few as six to eight deliveries or pickups per day (McDermott, 1973, p. 86; Truck-Taxi Survey, 1965, p. 27; Chappel and Smith, 1970, p. 169), even though the average distance traveled is less than 2.3 miles per delivery or pickup (Chappel and Smith, 1970, p. 169; Smith, 1969, p. 7).

Inefficient routing and a poor infrastructure of pickup and delivery among the carriers also leads to street
congestion. Small carriers are the primary components of the trucking industry; it is estimated that seventy percent of all commercially-owned trucks are in single truck "fleets", and less than ten percent are in fleets of more than twenty trucks (Smith, 1969, p. 4). Much route duplication occurs among these fleets. These trucks spend four hours per day idle in traffic (Goods Movement in the New York Region -- A Study Proposal, 1970, p. 1), with stops averaging forty-seven minutes and double parking averaging ten to twenty minutes (Smith, 1969, p. 90). They also spend an average of twenty-five percent of the carrier's time waiting to load or unload (McDermott, 1973, p. 64).

In addition to competition among freight vehicles, competition between freight and passenger vehicles for space and priority on streets in the CBD also occurs. Although trucks account for only ten percent of the total vehicles on the road during peak hours, they effectively represent about twenty percent or more of the total vehicles when converted into passenger vehicle equivalents (Smith, 1969; Chappel and Smith, 1970, p. 168). Trucks travel at very slow speeds in the CBD, averaging four to five miles per hour in transit (Goods Movement . . . ., 1970, p. 1; McDermott, 1975, p. 64). When the carriers make their pick-ups or deliveries in the CBD, they ordinarily park at the curb side, since only twelve percent of the CBD buildings in cities with populations greater than 500,000 have off-
street loading (Battelle, 1972, p. 50). In addition, the average rate of illegal parking is more than thirty-five percent, and may go as high as seventy-five percent (Smith, 1969, p. 90).

The third reason for interest in intraurban shipments in the CBD is their impact on the environment. The inefficient movement of goods in the urban center has contributed significantly to street congestion, air and noise pollution, and excessive consumption of fuel energy.

Trucks moving in the CBD have been identified as a major source of air and noise pollution. In midtown Manhattan trucks accounted for fifty percent of the vehicle-related pollutants, and in downtown Manhattan they accounted for more than sixty-five percent of pollutants (Ketchan, 1972, p. 75). In a study conducted in downtown Columbus, Ohio, McDermott estimated that on an average weekday more than 459 pounds of carbon monoxide, 107 pounds of hydrocarbons, and thirty-six pounds of nitrogen oxide are emitted by trucks making small shipments (McDermott, 1973, p. 68). A study on noise pollution conducted in Houston, Texas revealed that the noise caused by passing trucks in a high-rise area equaled ninety-four decibels (Battelle, 1972, p. 58), nineteen decibels above the level (seventy-five decibels) at which temporary psychological changes reportedly begin to occur (Hedges, 1971, p. 171). Also, in New York City seventy-five percent of noise pollution is attributable
to trucks (Proposal for Controlling Environmental Pollutants in New York City, 1972, p. 7).

Inefficient usage of fuel energy can be related to the incomplete capacity utilization of trucks making small shipments in the CBD. In Columbus, McDermott estimated that sixty percent of the shipments destined to or originating from the CBD were less than two-hundred pounds, and that more than ninety percent were less than one-thousand pounds (McDermott, 1973, pp. 55-56). The average capacity utilization of trucks making small shipments was about thirty-two percent (McDermott, 1973, pp. 83-84). In a similar study in the Tri-State area, it was also observed that the capacity utilization was less than fifty percent. It is estimated that the transportation of freight requires about one-eighth of all energy produced and one-fourth of the petroleum products in the United States (Energy Crises -- It is Happening, 1973, pp. 37 - 39); urban trucking and parcel delivery account for about six percent of the petroleum consumed in freight distribution (Rice, 1972, p. 31). The excessive consumption of fuel energy by the trucking industry is indirectly caused by street congestion, which indicates that a more efficient system of small shipments in the CBD would be helpful in meeting the energy shortage.

The situation of local trucking is thus called "wasteful" by one freight planner (Wood, 1974, p. 1). Efficient planning of local freight distribution is
urgently needed for all those concerned: the trucking industry, the shippers, and the public.

**Alternative Solutions to the Problem**

In accordance with these economic and environmental considerations, several alternative methods for handling small shipments in the CBD have been proposed. The most prominent of these alternatives are:

1. Spatial separation
2. Temporal separation
3. Required off-street loading/unloading facilities
4. Traffic engineering
5. Consolidation terminals

Spatial separation aims at a reduction in the competition between people and freight for transport capacity. It is designed to create exclusive rights-of-way for people and freight movements within an urban area (Battelle, 1972, p. 88). Temporal separation refers to the restricting of physical movements and curb-side loading/unloading of goods to those hours of the day and night during which people movement is minimal (Battelle, 1972, p. 94). Required off-street loading/unloading facilities involves the revision of building code and zoning to require the inclusion of adequate facilities for freight pickup and delivery (Battelle, 1972, p. 100). Traffic engineering calls for the
construction of new and/or wider streets or the restricting of vehicle access according to vehicle type, direction or time.¹

The concept of consolidation terminals demands that small shipments destined to or originating from a CBD be routed through a consolidation terminal. The consolidation terminal would coordinate all deliveries and pick-ups in the CBD. It would thus not only reduce the number of vehicles engaged in pick-ups and deliveries within the CBD, but also make it possible to perform these functions at a lower total cost to business and society. Therefore, as such, it may well be the most desirable of all the alternatives.

Although the concept of consolidation terminals promise great advantages over the existing small shipment system in the CBD, its development requires a high capital investment and long-run institutional change. Furthermore, some public carriers may perceive the consolidation terminal approach as professionally threatening (Taff, 1970, p. 44). To assess the relationship between the consolidation center and the carriers in serving small shipment needs in the CBD, a comprehensive study is necessary to gain better insight into the feasibility and desirability of this highly acclaimed

¹For more detailed analysis on these alternatives, readers are referred to the Battelle report, "Urban Goods Movement Program Design" (1972), pp. 88-102.

**Purpose of the Study**

This research study is one part of a three-part study of the social and economic feasibility of implementing the urban consolidation terminal. Part I concentrated on pick-up and delivery routings and examines the expected social and economic benefits of handling the small shipments through a consolidation terminal. This portion of the study has been completed by Dennis McDermott (1973).

Part II involved the (conceptual) design of terminal facilities. The long-range development of the terminal facilities to provide for the efficient operation of the terminal during the planning horizon was examined in this part of the study. The investment requirements in terms of size and timing, the trade-off of capital investment and efficiency of operation, and the sensitivity of demand on capacity planning were the major topics studied in Part II. Part II was completed by Ernest Cadotte (1974).

Part III is concerned with determining the number and locations of consolidation terminals within an urban area in terms of economic and environmental factors. The economic factors are related to the cost of the total system, while
the environmental factors are measured by street congestion, air and noise pollution, and the consumption of energy. The investigation conducted here is devoted to this third phase of the research.

McDermott's study (1973) has supported the economic and social feasibility and desirability of the consolidation terminal. McDermott constructed a simulation model to investigate the concept of the consolidation terminal in the Columbus, Ohio, CBD. The actual results are very much in line with the predicted results (Battelle, 1972, p. 36; Lovejoy, 1970, pp. 121-124; Woods and Leighton, 1969; Summary of Conference Proceedings, 1971, p. 9). McDermott indicated that a consolidation terminal for the Columbus CBD can reduce the number of trucks in the CBD by ninety percent, travel distance by ninety-one percent, transit time by ninety-one percent and unloading time by over ninety-five percent. All of this can be achieved at a cost saving of $8,410 daily, or $2,102,500 annually (1973, p. 108).  

McDermott's study assumed that the consolidation terminal would be located on the northern fringe of the Columbus CBD (1973, p. 96 and p. 190). The purpose of this study is to determine where one or more terminals should be

1These figures include only pickup and delivery changes and do not include terminal costs and handling costs.
located. In general, a decision on terminal location is final; once the decision is made, the capital expenditure and time frame involved are such that relocation is not feasible in the short run. Therefore, this study is to evaluate the economic factors and thus determine a suitable location for the consolidation truck terminal for small shipments in the CBD. This phase of the study looks into:

1. The number of terminals that should be located to serve the Columbus CBD

2. The optimum location of these terminals in terms of:
   a. Transportation cost from the consolidation terminal to customers in the CBD
   b. Transportation cost from the carriers (private and for-hire) to the consolidation terminal

3. The assignment of truck clusters and CBD zones¹ to the consolidated terminals

4. The implications that the research findings have for:
   a. The development of public policy and planning with respect to truck terminals

¹For the definitions and classifications of truck clusters and CBD zones, refer to Appendices A and B.
b. Areas of needed improvement in the private site selection process

c. Impact on site selection as shifts occur in the origins and destinations of the small shipments

Scope of Study

The scope of this study includes examination of general freight ranging up to 5,000 pounds and flowing into and out of the Columbus CBD by either private or public (for-hire) carriers stationed outside the CBD. Excluded from the scope of this study are bulk movements, perishable product shipments, and shipments transported by specialists in very small shipment distribution, namely the Postal Service, United Parcel Service, and the Railway Express Agency.

In addition to general freight up to 5,000 pounds, shipments of only less than 1,000 pounds are also considered, as McDermott recommended, since ninety percent of all shipments in the up-to 5,000 pounds category are less than 1,000 pounds and eighty-three percent of the expected savings for the consolidation terminal would be realized from consolidating pickup and delivery of shipments weighing less than 1,000 pounds. Therefore, in this study shipments of less than 1,000 pounds have been examined separately from the 5,000 pounds category.
The selection of terminal sites based on the current land use tax structure and the zoning system is investigated in this study. The impact of governmental policy on the variation of zoning and tax structure has not been investigated.

The study treats social costs (such as traffic congestion, air and noise pollution, and fuel energy consumption) as the dependent variables of the controllable economic operating cost. The economic cost is to a large extent determined by the cost of performing pickup and delivery service in the CBD, as well as between the carriers' terminals and the consolidation terminal, and the handling cost of the consolidation terminal. In McDermott's study, the pickup and delivery costs in the CBD were measured. His study is extended in this one to evaluate the cost necessary to perform the pickups and deliveries between the consolidation terminal and all carriers' terminals, and also the operating cost of the consolidation terminal(s).

Hypotheses

The research hypotheses are based on the purpose of the study discussed previously. Five major hypotheses have been constructed to determine the number and location of the consolidation terminals required for small shipments to serve the central business district of Columbus. Data
taken from McDermott's (1973) cordon crossing survey was used to construct demand generation for the analysis. Each major hypothesis is tested with respect to each system's operating cost, which is derived from the methodology developed in the study.

The objective of the first major hypothesis is to determine the number of terminals required for the urban consolidation terminal system. 

\[ H_0 - 1 \] There is no difference in economic benefits regardless of whether there is one central terminal or multiple terminals for the urban consolidation terminal system located in the outerbelt area.

This null hypothesis will specifically investigate the single terminal versus two, three, or four terminals in the metropolitan area. For the Columbus CBD, it is assumed that, at most, four consolidation terminals will be needed. If it is found that more than four terminals are desirable, the test of the hypothesis can be extended to include all the necessary cases.

The study also determines the location of the consolidation terminal. One of the basic objectives is to determine whether the terminal should be located in or near the CBD, or in the outerbelt area. The next hypothesis focuses on that issue.
There is no difference in economic benefits regardless of whether the consolidation terminal is located close to the CBD or in the outerbelt area.

This hypothesis is addressed to the single terminal issue only, since more than one consolidation terminal in or near the CBD is not considered feasible, particularly in the Columbus case, where the CBD is located within a relatively small area.

In combination with hypothesis one and hypothesis two, the next hypothesis determines whether a single terminal should be located in the downtown area, or whether multiple terminals should be located in the outerbelt area. The null hypothesis is stated as follows:

There is no difference in economic benefits regarding the location of either the single consolidation terminal in downtown or multiple terminals in the outerbelt area.

Through the testing of these hypotheses, the study presents the final findings regarding the number and locations of the consolidation terminals. Then an analysis of the commodity scope of general freight up to 5,000 pounds, versus the scope of small shipments under 1,000 pounds, is made to determine their impact on system cost. Thus, the null hypothesis is formulated as follows:
There is no difference in economic benefits regardless of whether the commodity scope is up to 5,000 pounds or under 1,000 pounds.

The number and location of the consolidation terminals are analyzed respectively by testing the hypotheses stated above. The locations of the small shipment requirements within the CBD and the inbound and outbound requirements through carriers' terminals were held constant in each of the previous analyses. At this step, the study determines the impact of shifting the locations of demand requirements on the system cost of the consolidation terminal locations. This research step approaches the issue by focusing on the following null hypothesis:

There is no difference in the location of the consolidation terminal when truck operator terminals shift their locations to the vicinity of the consolidation terminal(s).

Criteria for the acceptance or rejection of the above null hypothesis are based on whether the percentage of variation is within or beyond five percent over the smallest cost configuration.
Methodology

The primary analytical tool for the study is a heuristic nonlinear mathematical programming model depicting the relationship among demand requirements, operating costs of the consolidation terminal, and transportation costs between the consolidation terminal and the CBD customers as well as among the freight carriers. The model is used to evaluate the number and locations of consolidation terminals in terms of economic system costs.

The data base for the demand requirements in the CBD, as well as for inbound and outbound transhipment requirements, is constructed from a cordon crossing study conducted by McDermott on November 16 and 17, 1972, in Columbus, Ohio. A demand distribution is developed from this data base, replicating both the private and public terminals' shipments, destination, and origins within or beyond the CBD. (Appendix B)

For the research analysis design, a feasible set of alternative terminal locations is constructed. These candidate locations are selected from both existing sites and potential sites of land area currently being zoned for industrial use.

The mathematical model incorporates all of the following:
1. Locations of the demands
   a. Pickup and delivery requirements of shipments in the CBD
   b. Pickup and delivery requirements of small shipments destined to or originating from private and public terminals

2. Delivery and pickup costs as an anticipated function of the following variables
   a. Routing of delivery and pickup
   b. Distance between the consolidation terminal and the destination
   c. State of traffic flow
   d. Queuing at delivery and pickup docks

3. Capacity investment requirements
   a. Single consolidation terminal
   b. Multiple consolidation terminals

The objective of the research analysis is to select the appropriate number of consolidation terminals, assign to each of them the CBD zones and truck clusters to be served, and locate the terminals in sites which will result in minimum system cost.

The developed mathematical programming model, coupled with the solution algorithms, are used to select the most effective low cost location or set of locations for the test of the hypothesis. Since the model is constructed with a deterministic data base, the model is therefore
analyzed in a deterministic manner. As such, in determining the system cost for each alternative, a heuristic solution is generated.

Potential Contributions of the Study

The potential contributions of the research study can be viewed from the following perspectives: management of small shipments, city planning, research methodology, and location theory development.

1. Contribution to the Management of Small Shipments

The research study, as stated earlier, is one part of a three-part study which evaluates the economic and social feasibility of implementing the urban consolidation terminal system for small shipments in the CBD. The study's contribution to the small shipment management is to demonstrate the relationship between the consolidation terminal location and the performance of the terminal in terms of local distribution efficiency and economic benefits. Furthermore, the study determines for management the appropriate number and locations of the consolidation terminals.

2. Contribution to the City Planners

Consolidation freight shipment is characterized by pickup and delivery service to the shippers and consignee, as well as transshipment from the consolidation terminal to
the truck operators' terminals in the Columbus CBD. The findings of the research study would further illuminate the planning of terminal locations for carriers as an integral part of comprehensive transportation planning for the urban area, including the planning of a transportation system which better handles the movement of people as well as freight. This planning could be facilitated by the possible relocation of trucking operators' terminals in an effort to minimize costs of transhipment between these terminals and the consolidation terminal.

3. **Contribution to the Location Theory**

Location analysis of the consolidation terminal is being formulated as an integer programming problem. The development and demonstration of the research model on the application of an efficient special case of integer programming will aid the advancement of the location theory.

**Limitations of the Study**

1. The study is limited to location selection for the consolidation terminal only. As previously stated, the scope of the study is limited to small shipments of general commodities up to 5,000 pounds and also, in a separate case, to shipments of less than 1,000 pounds. The investigation is directed toward location selection for the truck terminal
performing the small shipment consolidation. The intermodal use of terminal areas is not investigated.

2. The research study is limited to the investigation of the economic and social benefits of the consolidation terminal location. A consolidation terminal may have a significant effect on regional development; however, since it is beyond the scope of this study, the impact of the consolidation terminal on regional development is not investigated.

Although the research study is limited to cities having a similar highway system and freight distribution characteristics as Columbus, Ohio, the model may be applied to cities where parameters have been duly adjusted.

Organization of the Research

Chapter I presents the statement of the problem, the research hypotheses, and the study's scope, purpose, contributions, and limitations.

Chapter II summarizes the results of the literature review upon which the study is based. The chapter focuses on the formulation of techniques for solving the location analysis problem.

Chapter III presents the research design and methodology of the study. The chapter focuses on the determination of the functional relationships between the pertinent
variables and considers the development of the mathematical model for the study.

Chapter IV contains the findings of the study. The results of the tests of the research hypotheses and other findings are presented.

Chapter V contains a general summary of the study and presents the conclusions and implications drawn from the hypothesis test results and other findings. The conclusions and implications are discussed with respect to terminal site selection. The chapter concludes with recommendations for further research.
CHAPTER II

LOCATION ANALYSIS AND CONSOLIDATION TERMINAL ALLOCATION: CONTRIBUTIONS FROM THE LITERATURE

The objective of this chapter is to present, in two sections, a survey of the literature relevant to this study. The first section reviews the development of the general theory of location and space economy. Section two examines the various analytical techniques that have been developed for facility site selection. It then defines the related variables, measurements, and formulation of terminal site selection as an equivalent location analysis problem.

The Location Theory and Space Economy

The first attempt to construct a formal location theory is generally attributed to the German economist, Alfred Weber, in his major work published in 1909 (Friedrich, 1929, Alfred Weber's Theory of the Location of Industries). However, considerable progress toward location analysis was made in the middle of the nineteenth century by another German writer, Johann Heinrich Von Thünen, who dealt with the agricultural location problem (Von Thünen, 1826). Von Thünen restricted himself exclusively to the
problem of explaining the distribution of various kinds of
agricultural activity within a given homogeneous territory,
and he treated transport expense as the primary factor ex­
plaining production location of different agricultural
commodities.

Weber took an evolutionary approach. He expanded his
theoretical system, which included agricultural and in­
dustrial strata, to encompass a larger economic state. He
examined the flow of both raw materials and finished prod­
ucts necessary to industrial production and marketing. He
classified materials from the standpoint of their role in
the manufacturing process in order to determine their rela­
tive priorities with regard to transportation. Furthermore,
by using the required transportation cost as an index, he
analyzed the question of how to ascertain the optimum loca­
tion of a firm between a source of raw materials and a market.

Weber next formulated a "material index" which is
defined as the ratio of the weight of localized raw materi­
als¹ to the weight of the finished product. Through the use
of the material index, Weber developed three theorems:

1. All industries involved in weight-gaining
   processes will locate at the point of
   consumption

¹The raw materials that are found in an unique
location.
2. All industries involved in weight-losing processes will locate at the point of production.

3. All industries in which the weight gain and weight loss balance each other, or are not considered important, will locate at some point in between.

Thus, Weber proposed that the location of an industry is primarily dependent upon transportation costs. In developing his theory, he made four major assumptions: (1) uniform freight rates as a function of distance and weight, (2) equal costs of raw materials at the site of their deposit, (3) uneven distribution of raw material deposits, and (4) the dispersal of many consuming centers throughout the economy (Friedrich, 1929, p. 69).

Edgar Hoover (1948), an early American space economist, followed Von Thunen and Weber in advancing an explanation of industrial location within a purely competitive framework. Hoover separated the cost factors of location into two groups: production factors and transportation factors. The cost of procuring raw materials, the cost of distributing the agglomerative forces, and institutional costs were treated as partial determinants of production costs.

Hoover stressed the fact that the cost of transport is not proportional with distance; rather, additional transit
costs are less than proportional as the distance increases. He emphasized this nonproportionality, along with the heterogeneous character of the distribution of economic factors and the institutional forces effecting transportation cost. The result of Hoover's analysis was to show that these influences resulted in irregularly-shaped market territories.

While Hoover's analysis afforded valuable insight into the forces determining the number and size of producers, the problems of maximum size and localization or dispersion remained largely unsolved. An endeavor in these directions was made a few years later by August Losch, another German space economist, in his Die raumliche Ordnung der Wirtschaft (1944). For his analysis Losch followed Von Thünen's assumptions of homogeneous characteristics. Specifically, these assumptions are: (1) uniform transport features in all directions, and (2) an even distribution of agricultural population throughout a plane, each individual having identical taste, preference, technical knowledge, and production opportunities. But Losch was the first to incorporate an element of imperfect competition in economic space analysis.

Losch's main contributions are the definition of a firm's minimum size market area, and a view of industrial agglomeration. But he failed to analyze locational interdependence. Losch, as did his predecessors, placed emphasis upon optimality based on cost consideration.
Economist Melvin Greenhut (1956) was among the first to point out that demand, in addition to cost, has an important effect on location decisions and space allocation. All previous writers had primarily assumed that a constant demand existed, which resulted in cost being the sole determinant of space allocation and plant location.

Greenhut suggests that industrial agglomeration is partially determined by: (1) the shape of demand curve, (2) the shape of the marginal cost curves, (3) the height of the freight rates, and (4) the degree and type of competition in the industry, which in itself is largely influenced by these other factors. He demonstrates that in certain situations the demand curve may alone be so influential as to overrule the other determinants. Conversely, where the demand curve is relegated to a relatively subordinate role by assuming neither infinite elasticity nor inelasticity, the freight rate or the marginal cost of production may alone determine the locational competitiveness of the industry (Greenhut, 1956, pp. 147 - 148).

The location and space economy analysis that has been rapidly developing into the new discipline of regional science is largely due to the pioneer contribution of Walter Isard (1956, 1960). Regional science interrelates industrial location, market areas, land use, trade, and urban structure. Its main focus is the integration of location study with regional equilibrium. Isard and his followers
have made much progress in this field in recent years (Isard, 1956; Airov, 1956; Isard, et. al., 1960; Miller, 1961).

**Fixed Facility Location Analysis**

Location analysis has used two different approaches in its theoretical development. One approach traces the evolution of theories from Weber to Isard in a search for a general equilibrium theory for location and space economy, as is discussed in the previous section. The other approach seeks an efficient method of selecting the site(s) of least cost for fixed facility allocation. This latter approach, based upon Weber's classic study of the location of industries, investigates the methods and approaches to be used in locating fixed facility sites. This fixed facility location analysis, often referred to as plant or warehouse location analysis, seeks to select the optimal locations of central facilities that would satisfy all the demand and supply requirements at the lowest total system cost or maximum total system profits.

As a pure mathematical problem of selecting a central point that would provide the shortest distance to and from the various outlay points, location analysis can be dated back long before Alfred Weber. As early as 1647, Cavalier (Cooper, 1965) tried to find the point at which the sum of
its distances from three given points is at a minimum.

In 1834 Heinen (Cooper, 1963) examined a special case of a triangular (three points) problem. In 1775 Fagnano (Cooper, 1963) extended the problem to a quadrilateral (four points) problem. In 1810 Tedenat (Cooper, 1963) further extended it into an n points problem, and established a necessary condition for a minimum point. And finally, in 1837 Stiner (Cooper, 1963) established and proved the necessary and sufficient conditions for the n points problem.

A fixed facility problem can be classified into two major structural categories: the infinite set approach and the finite set approach.

Infinite Set Approach

The infinite set approach assumes that the central facilities may be located anywhere on a plane, and that the distance measurement corresponds to a particular metric, such as the Euclidean or metropolitan metric. In general, the model requires the following parameters:

1. Demand point coordinates
2. Demand quantity
3. Transportation costs expressed as costs per unit distance, or per unit weight distance
4. Capital depreciation and operating costs of facility sites
The model is formulated to minimize

\[ C = \sum_{i}^{n} \sum_{p}^{m} a_{ip} W_{ip} d_{ip} + \sum_{p}^{m} f_{p} (Z_{p}) \]  \[1\]

Subject to

\[ [ (X_{i} - X_{p})^{2} + (Y_{i} - Y_{p})^{2} ]^{1/2} = d_{ip} \]  \[2\]

Where

\[ a_{ip} = \begin{cases} 1, & \text{if point } i \text{ is served by central point } p, \\ 0, & \text{otherwise}; \end{cases} \]

\[ W_{ip} = \text{the weight attached to the } i \text{ th point} \]
\( (\text{goods demanded, resources sent, populations, etc.}), \text{to point } p; \)

\[ X_{i}, Y_{i} = \text{the location of the } i \text{ th point relative to some fixed Cartesian coordinate system}; \]

\[ X_{p}, Y_{p} = \text{The unknown coordinates of the central facility } p; \]

\[ n = \text{the number of points which are served}; \]

\[ m = \text{the number of central facilities}; \text{ and} \]

\[ d_{ip} = \text{the Euclidean distance from point } i \text{ to the central facility } p; \]

\[ f_{p} = \text{operating cost function}; \text{ and} \]

\[ Z_{p} = \text{size of facility which is determined by} \]

\[ \sum_{i}^{n} W_{ip}. \]

Equation [1] measures the total system cost, which consists of the transportation cost satisfying all the
demand and supply requirements, and the facility operating
costs. Equation [2] defines the distance from central
facilities to all points of demand as Euclidean distance.

This model is an extension of Weber's classic location
problem. Miehle (1958) and Wester and Kanter (1958) indepen­
dently formulated and described an iterative process for
solving this problem with equation [1] minimizing the trans­
portation cost only. Later Cooper (1963) and Kuhn and Kuenne
(1963) also investigated the same location problem, but from
a slightly different angle. Cooper suggested a heuristic
process which considered both the multiple facility and the
facility operating cost.

The iterative solution process for each of the above-
mentioned works begin by taking the partial derivatives of
equations [1] for the transportation cost with respect to
\( X_p \) and \( Y_p \), which yield a pair of extremals:

\[
\frac{\partial C}{\partial X_p} = \sum_{i} \frac{a_{ip} \ W_{ip} (X_i - X_p)}{d_{ip}} = 0, \quad \text{(3)}
\]

\[
\frac{\partial C}{\partial Y_p} = \sum_{i} \frac{a_{ip} \ W_{ip} (Y_i - Y_p)}{d_{ip}} = 0. \quad \text{(4)}
\]

Since this pair of equations has no direct solution
for the variables \( X_p \) and \( Y_p \), a set of initial locations is
selected and iteratively improved upon until convergence is
reached. Cooper (1963) suggested starting with the weighted
mean coordinates:

\[ X^0_p = \frac{\sum_{i=1}^{n} a_{ip} W_{ip} X_i}{\sum_{i=1}^{n} a_{ip}} \] \[ \tag{5} \]

\[ Y^0_p = \frac{\sum_{i=1}^{n} a_{ip} W_{ip} Y_i}{\sum_{i=1}^{n} a_{ip}} \] \[ \tag{6} \]

The iterative procedure suggested by Cooper and others is to solve [3] and [4] for \( X_p \) and \( Y_p \) in terms of \( a_{ip}, W_{ip}, X_i, Y_i, \) and \( d_{ip} \):

\[ X_p = \frac{\sum_{i=1}^{n} (a_{ip} W_{ip} X_i/d_{ip})}{\sum_{i=1}^{n} (a_{ip} W_{ip}/d_{ip})} \] \[ \tag{7} \]

\[ Y_p = \frac{\sum_{i=1}^{n} (a_{ip} W_{ip} Y_i/d_{ip})}{\sum_{i=1}^{n} (a_{ip} W_{ip}/d_{ip})} \] \[ \tag{8} \]

The value of \( d_{ip} \) is then recalculated via [2] and the procedure repeated until successive differences between values of \( X_p \) and between values of \( Y_p \) are negligible.

In this iterative procedure the fact that equation [1] is convergent in the case of a single central facility has been shown by Haley (1963), Kuhn and Kuenne (1963),
and Palermo (1961); the cost function, being convex, has a single unique optimal solution. Equation [1] is also convergent for the multi-facility case, as well as being the sum of the m (m > 1) convergent equation.

Since the cost function is continuous, the infinite set approach has great flexibility; it can be used to select the optimum locations of all the facilities in the system. It is also comparatively simple to conduct sensitivity tests on the change of parameters.

Infinite set approach, on the other hand, suffers some shortcomings. First, in reality transportation costs are often not linearly related to the distance traveled, particularly to straight line distance. Second, the operating cost of a central facility is often a function of its location due to existing differentials in rentals, wages and other costs among various geographical locations. Third, there are economies of scale in the operation of a central facility and, as its size may depend on its location, the operating costs are further affected. Finally, there is a host of qualitative factors unrelated to transportation and operating costs that make certain location patterns undesirable. In order to handle such shortcomings, many space economists have proposed the feasible set approach.
The Feasible Set Approach

The feasible set approach is to select a number of locations which are known to be feasible, and for which can be determined the actual costs of transportation to each customer and the operating costs that depend on local conditions. The problem is then to select from this set of feasible sites the subset of facilities that results in minimum total system cost. The general mathematical formulation of the facility location problem for the feasible set is:

Minimize \[ C = \sum_{i}^{m} \sum_{j}^{n} d_{ij}(x_{ij}) + \sum_{i}^{m} F_{i}(y_{i}) \] \[ i \] \[ j \] \[ [9] \]

Subject to \[ \sum_{j}^{n} x_{ij} = y_{i} \] \[ i = 1,2,...,m \] \[ [10] \]

\[ \sum_{i}^{m} x_{ij} = D_{j} \] \[ j = 1,2,...,n \] \[ [11] \]

\[ x_{ij} \geq 0 \] \[ \{ \] \[ i = 1,2,...,m \] \[ j = 1,2,...,n \] \[ [12] \]

\[ y_{i} \geq 0 \] \[ i = 1,2,...,m \]

where

\[ x_{ij} = \] amount shipped from central facility \( i \) to demand \( j \);

\[ y_{i} = \] total amount shipped from central facility \( i \);
Equation [9] seeks to minimize the sum of the transportation cost and the amortized facility cost; Equation [10] equates the size of a central facility to the volume of its shipments, and Equation [11] seeks to guarantee that the total amount of demand will be satisfied by all of the central facilities. Kuehn and Hamburger (1963) assume that transport costs are linear regarding the amount shipped and that facility costs are of the form

\[ F_i(y_i) = \begin{cases} a_i + b_i y_i, & \text{when } y_i > 0, \\ 0, & \text{otherwise.} \end{cases} \]

\[ F_i(y_i) = \{ a_i + b_i y_i, \text{ when } y_i > 0, \}

F_i(y_i) consists of a fixed charge that is independent of storage and a linear cost (b_i) which depends on the volume handled if facility exists. Thus, the formulation of the objective function [12] becomes the following:

\[
\text{Minimize } C = \sum_{i=1}^{m} \sum_{j=1}^{n} (d_{ij} + b_i) x_{ij} + \sum_{i=1}^{m} F_i a_i y_i
\]

subject to the restrictions [10] through [13]. When the
expansion cost $b_i$ is assumed to be constant for each facility, the demand area which a given facility will serve will be determined automatically, by simply selecting a demand area for that facility for which the sum of shipment cost and expansion cost is minimum.\(^1\)

Kuehn and Hamburger use the following three heuristics in forming their algorithm:

1. Good locations for regional warehouses will be at or near concentrations of demand. Therefore, only the largest demand points need be considered as potential warehouse locations, thereby eliminating any isolated areas from consideration.

2. The solution method begins with a single facility, and another facility is added to see if the total cost can be decreased. Thus, at each stage only that facility which offers the biggest improvement is added to the set of facilities being used. The algorithm terminates when no more improvements are possible.

3. At each stage, only a small subset of the large

\(^1\)This is true only if there are no economies (diseconomies) of scale and no capacity restrictions on the facilities.
set of all potential facilities need be considered for detailed evaluation.

Feldman, Lehrer, and Ray (1966) allow the economies of scale to affect the warehousing costs over the entire range of warehouse; function $F_i(y_i)$ is assumed to be continuous and concave over the range of interest. Their extensions to the Keuhn and Hamburger work consist of developing additional heuristics to meet the non-linearities arising due to the warehousing costs. They suggest the use of the "drop" approach, which consists of starting with all the potential warehouses open and "dropping" (closing) one warehouse at a time until a local optimum set is reached. They claim near optimal performance and propose that optimal scale and location of facilities are quite sensitive to the shapes of the particular cost functions employed.

Although the heuristic method allows great model building flexibility, there is no way to know how far the answer obtained is from the optimal solution. Because of this difficulty and the additional difficulty of performing sensitivity analysis using a heuristic method, another approach was taken by Baumol and Wolfe (1958).

Baumol and Wolfe recognized the nonlinear nature of the cost situation in determining the facility location. The sources of nonlinearity arise from several causes. First, the transportation rate structure is nonlinear; for
instance, less than a full carload shipment will move at higher rates. Second, some of the warehousing contracts also involve similar rate structure changes. Third, the use of additional facilities increases negotiation, bookkeeping, and administrative costs. And finally, there are usually economies of large scale facility operations. Therefore, Baumol and Wolfe formulate their objective function as a concave function which minimize

\[
C = \sum_{i}^{m} \sum_{j}^{n} \sum_{k}^{p} (c_{ij} + d_{jk})x_{ijk} + \sum_{j}^{n} W_{j}(z_{j}) + \sum_{j}^{n} V_{j}r(z_{j})
\]  

[14]

Subject to:

\[
\sum_{j}^{n} \sum_{k}^{p} x_{ijk} = Q_{i} \quad i = 1, 2, \ldots, m \]  

[15]

\[
\sum_{i}^{m} \sum_{k}^{p} a_{ijk}(x_{ijk}) = R_{j} \quad j = 1, 2, \ldots, n \]  

[16]

\[
\sum_{i}^{m} \sum_{j}^{n} x_{ijk} = S_{k} \quad k = 1, 2, \ldots, p \]  

[17]

\[
x_{ijk} \geq 0 \quad \text{all } i, j, \text{ and } k. \]  

[18]

where

\[x_{ijk}\] = the quantity shipped from factory i via warehouse j, to retailer location k;

\[c_{ij}\] = the unit cost of transportation from factory i to warehouse j;
\[ \begin{align*}
\text{d}_{jk} & \text{ = the unit cost of transportation from warehouse j to retailer k;} \\
W_j & \text{ = the cost of storage per case per period;} \\
Z_j & \text{ = } \sum_{i} \sum_{k} x_{ijk} \text{ = the total flow through warehouse j;} \\
q & \text{ = (0 < q < i), a constant;} \\
v_j & \text{ = the administrative cost of warehouse j,} \\
r & \text{ = } \begin{cases} 1, & \text{if } \sum_{i} \sum_{k} x_{ijk} > 0, \\ 0, & \text{otherwise;} \end{cases} \\
Q_i & \text{ = the quantity shipped from plant i;} \\
a_{ijk}(x_{ijk}) & \text{ = the amount of volume at warehouse j contributed as a result of the flow } x_{ijk}; \\
R_j & \text{ = the capacity of warehouse j;} \text{ and} \\
S_k & \text{ = the quantity required at destination k.} 
\end{align*} \]

Since the nonlinearity may be expected to appear in the objective function, Equation [14], and in the warehouse capacity constraints, Equation [15], if they are relevant, Baumol and Wolfe suggest an iterative procedure which solves the warehouse-location problem in two stages. The first stage consists of only the linear costs of the objective function, while ignoring the warehouse loading charges and administrative costs. This problem is thus solved by the ordinary transportation algorithm. In the second stage, the warehouse loading charges are considered. The process is repeated until no improvement is made in the new iteration.
Although they do not claim that their procedure will always terminate at the optimal solution, they state that their final solution will be a local optimum. The assumption of known demand at each geographical region is used, while at the same time allowing the number of warehouses to vary. This method appears to have some advantages. First, it may use nonlinear (i.e., concave) cost functions. Second, it can utilize the transportation algorithm. And third, it might also be possible to extend this model to the multi-product problem.

Balinski and Mills (1960) assume the total warehousing costs to be a piece-wise linear function of the goods processed through the warehouse. Their technique consists of approximating the piece-wise linear warehousing cost function by averaging per unit cost of operating the warehouse at some high level (such as the capacity of the warehouse or the yearly volume of throughput at the warehouse). This approximation enables them to solve the problem as a simple linear transportation problem and thus obtain bounds on the optimal solution.

Efroymson and Ray (1966) presented branch and bound algorithm to determine the optimal solution to a related, but more constrained problem. They assume the total warehousing costs to be composed of the fixed warehousing costs, independent of the volume of goods processed through the
warehouse, and either a single fixed charge or a fixed charge plus an expansion cost, and a per unit variable warehouse cost.

Their formulation of the problem is

Minimize \[ C = \sum_{i}^{m} \sum_{j}^{n} d_{ij} x_{ij} + \sum_{i}^{m} f_{i} y_{i} \]  \hspace{1cm} [19]

Subject to \[ \sum_{i \in N_{j}} x_{ij} = 1 \] \hspace{1cm} \[ j = 1,2,\ldots,n \]  \hspace{1cm} [20]

\[ \sum_{j \in P_{i}} x_{ij} \leq n_{i} y_{i} \] \hspace{1cm} \[ i = 1,2,\ldots,m \]  \hspace{1cm} [21]

\[ x_{ij}, y_{i} = (0,1) \] \hspace{1cm} \[ \{ j = 1,2,\ldots,n \} \]  \hspace{1cm} [22]

where

\( d_{ij} \) = cost of supplying the entire demand of area \( j \) from the warehouse at \( i \);

\( f_{i} \) = fixed charge for establishing a warehouse at \( i \);

\( y_{i} \) = 1 if the warehouse at \( i \) is established, 0 if not;

\( x_{ij} \) = the fraction of the demand of area \( j \) which is met by a warehouse at \( i \);

\( m \) = number of possible warehouse sites;

\( n \) = total number of demand areas;

\( P_{i} \) = the set of markets that can be supplied by a facility at \( i \);
\[ n_i \quad = \quad \text{the number of markets in } P_i; \quad \text{and} \]
\[ N_j \quad = \quad \text{the set of facilities that can supply market area } j. \]

The branch and bound algorithm, as Efroymson and Ray formulated, can terminate optimally, and the solution can be independent of all non-linearities in the transport cost function.

Spielburg (1969) also presented a branch and bound algorithm for plant location with many added features which decrease computation time. He suggested several extensions to the problem such as budget constraints on the local expenditure for facilities and mutually exclusive alternatives.

Khumawala (1972) developed an efficient branch and bound algorithm warehouse location problem. He assigned eight branching decision rules, which in his experience had greatly reduced the computer time needed to reach an optimal solution.

A major limitation of the branch and bound algorithm is the amount of computer storage required to store all the eligible nonterminal nodes and associated information. However, this problem may be solved in stages by judiciously deleting nodes no longer necessary for the algorithm for a large problem. Extreme care must be taken in designing such a procedure.

In place of mathematical programming approaches,
Shycon and Maffei (1960) suggested the use of simulation as a means of solving the warehouse location problem. Simulation allows the incorporation of many complexities of the real world and thus eliminates the approximation that the other techniques use to solve the problem. The disadvantage, however, is that simulation methods often become expensive, and the solution obtained may not be optimal. The effectiveness is therefore measured in terms of how well the simulation model describes the system under study, the "quality" of the solutions, and the costs of simulation.

Consolidation Terminal Site Selection Model

The consolidation terminal site selection problem is a special case of the central facility location problem. However, it differs from the latter in several ways. First, unlike the warehouse location problem where demand usually is spread over a large geographical area, often nationwide in nature, the geographical scope of the central business district in an urban center is a very small area.

Secondly, in the warehouse or plant location problem, the sources are usually limited in number, whereas the consolidation terminal site problem is dealing with many sources. There are many private and for-hire truck operators conducting delivery and pickup service for the small shipment in the CBD. Each of these truckers constitutes a shipment
source for the consolidation terminal.

Third, the potential sites of the consolidation terminal can be more precisely identified and determined. Since a consolidation terminal takes a large land area to construct and must have easy access to the CBD and to the private and for-hire truck operators, the potential sites will be in the available land area adjacent to the main arteries of the highway system in a metropolitan area.

Finally, while the availability of labor can be a major factor in determining plant location, terminal sites will not be so sensitive to that factor because the locations of the consolidation terminals will be distributed throughout the same metropolitan area.

In order to design a mathematical model of the consolidation terminal site selection problem which will comply with the foregoing characteristics, it is proposed here that the CBD be classified into smaller zones. Since the routing of pickup and delivery is crucial for efficient service in the CBD, the zones will be designated so as to give an efficient routing of pickup and delivery service.

However, pickup and delivery service is only half of the total coordinating service which the consolidation terminal will offer. The terminal must also consolidate shipments to and from the private and for-hire carriers, which exist in clusters spread throughout the metropolitan area.
The consolidation terminal site selection model can be formulated as follows:

\[
\text{Minimize } \sum_{i} a_i y_i + \sum_{i} b_i s_i + \sum_{i} \sum_{j} c_{ij} x_{ij} + \sum_{i} \sum_{j} d_{ij} z_{ij} + 1/2 \sum_{f} \sum_{k} \sum_{j} e_{fkj} w_{fkj} \]

Subject to:

\[
\sum_{i} x_{ij} = 1, \quad j = 1, 2, \ldots, n \tag{24} \]

\[
\sum_{i} z_{if} = 1, \quad f = 1, 2, \ldots, p \tag{25} \]

\[
\sum_{i} y_i = t, \tag{26} \]

\[
\sum_{i} z_{if} + \sum_{j} x_{ij} \leq u y_i, \quad i = 1, 2, \ldots, m \tag{27} \]

\[
\sum_{i} z_{if} \geq v y_i, \quad i = 1, 2, \ldots, m \tag{28} \]

\[
\sum_{i} x_{ij} \geq r y_i, \quad i = 1, 2, \ldots, m \tag{29} \]

\[
z_{kf} + x_{kj} - w_{fkj} = 1, \quad k, \ell = 1, 2, \ldots, m; k \neq \ell, \quad \{f = 1, 2, \ldots, p; j = 1, 2, \ldots, n \tag{30} \]

\[
y_i \leq 1, \tag{31} \]

\[
a_i \sum_{j} x_{ij} + \frac{1}{z_{\sum_{f} e_{kjl}}} (\beta_{ij} w_{kjl} + \gamma_{ij} w_{kjl}) = s_i, \quad i = 1, 2, \ldots, m \tag{32} \]
\[ X_{ij}, Z_{ij}, Y_i, W_{fklj} = (0,1) \text{ all } i,j,k,l,f, \quad k \neq l \]  

\( a_i \) = fixed cost of operating terminal \( Y_i \) if a terminal is established at site \( i \);

\( b_i \) = unit variable cost of operating terminal \( Y_i \) (the total variable cost of operating terminal \( Y_i \) is measured by \( b_i S_i \));

\( Y_i \) = 0, if no consolidation terminal at site \( i \),

\( Y_i \) = 1, if consolidation terminal is located at site \( i \);

\( c_{ij} \) = cost of shipping all volume of CBD zone \( j \) from consolidation terminal \( i \);

\( 0, \text{ CBD zone } j \text{ is not served by } Y_i, \)

\( 1, \text{ CBD zone } j \text{ is served by } Y_i; \)

\( d_{if} \) = cost of shipping all volume of truck operator cluster \( f \) to consolidation terminal \( i \);

\( 0, \text{ truck operator cluster } f \text{ is not served by } Y_i, \)

\( 1, \text{ cluster } f \text{ is being served by } Y_i;\)

\( e_{fklj} \) = cost of transhipping all volume from \( Y_k \) to \( Y_l \) (\( Y_k \neq Y_l \)) received by consolidation terminal \( k \) from truck cluster \( f \) to consolidation terminal \( l \) for ultimate delivery to CBD zone \( j \);

\( 1, \text{ transhipment between } Y_k \text{ and } Y_l \text{ involved cluster } f \text{ and zone } j, \)

\( W_{fklj} \) = 0, otherwise;
\( t \) = number of consolidation terminals designated for the run (it may be varied from 1 to 4 in this research analysis);

\[ S_i \] = total volume of shipment process at terminal \( Y_i \);

\( m \) = the total number of possible consolidation terminal sites;

\( n \) = total number of the CBD zones;

\( p \) = total number of the truck operator clusters;

\( u \) = a parameter which in conjunction with equation [27] forces \( Y_i \) to take a nonzero value if a terminal is established at site \( i \);

\( v \) = a parameter which defines the minimal number of truck operator clusters to be served by \( Y_i \) if a terminal is established at site \( i \);

\( r \) = a parameter which defines the minimum number of the CBD zones to be served by \( Y_i \) if a terminal is established at site \( i \);

\[ a_i \] = shipment volume destined to and originated from the terminal \( i \);

\[ b_i \] = shipment volume pickup by terminal \( i \) from truck cluster being transhipped to terminal \( i \); and
\[ Y_i \] is the shipment volume transhipped from terminal \( \varepsilon \) to terminal \( i \) to be delivered to truck cluster \( f \).

Equation [23] seeks to minimize the total cost of the consolidation terminal system, which is the sum of total delivery and pickup costs between the consolidation terminals and the customers in the CBD, the total delivery and pickup costs between the consolidation terminals and truck operators, the transhipment cost among the consolidation terminals when there are multiple consolidation terminals, and the operating cost of the terminals.

Equation [24] specifies, in conjunction with Equation [29] that each CBD zone must be served, and by only one consolidation terminal. Similarly, Equations [25] and [31] require that each truck cluster must be assigned to one CBD zone and one consolidation terminal.

Equation [26] defines the number of consolidation terminals required to serve the CBD. This constraint allows the experiment of one, two, three, or four consolidation terminals by varying the value of \( t \), so as to determine the impact on the total system cost.

Equation [27] serves two purposes. It forces a non-zero value of \( Y_i \) whenever a terminal is established at site \( i \), i.e., whenever the terminal is assigned to one or more
truck clusters or CBD zones.\(^1\) Also, this constraint places the upper limit of consolidation terminal capacity in terms of the number of CBD zones and truck operators being served by the consolidation terminal. In the case of the multiple consolidation terminal, if it is desirable to have a consolidation terminal serve no more than five CBD zones and truck clusters, then the righthand side value of \(u\) should be replaced by 5.

Equations [28] and [29] set the lower limit of a terminal's capacity, if it is established. Since a consolidation terminal requires a heavy capital investment, it is imperative to set a minimum number of CBD zones and truck operator clusters to be served by the consolidation terminal.\(^2\)

Equation [30] determines the amount of transhipment that must take place between consolidation terminals. Such shipments are necessitated whenever the shipments originating from (destined to) a truck cluster assigned to

\(^1\)Coupled with Equation [32], it forces \(Y_i\) to be 1 under such circumstances.

\(^2\)It could be argued that these constraints are superfluous, since investment costs are already included in Equation [25]. However, it sometimes is desirable to consider cases where there are more than the "optimal" number of consolidation terminals. Examples of such a motivation are (1) the need for sensitivity analysis on alternate designs and (2) qualitative considerations ignored by the model. If in such cases Equations [28] and [29] are not present, the best solution could call for the establishment of "dummy" terminals to which no truck cluster or CBD zones are assigned.
consolidation terminal No. 1 are destined for (originating from) a CBD zone assigned to consolidation terminal No. 2. This constraint is absent from the model whenever \( t = 1 \).

Equation [31] insures that the \( Y_i \) value will never be greater than 1. This set of equation is needed when the problem is solved heuristically using a linear programming algorithm. It is not, however, needed when solved by 0-1 algorithm.

Equation [32] accumulates the total shipment volume process at terminal \( Y_i \). The shipment volume includes the shipment pickup and delivery to the CBD zones \( X_{ij} \), and the transhipment from terminal \( i \) to terminal \( i \), or vice versa, which are destined to or originated from truck cluster \( Z_{if} \).

Equation [33] defines all variables as 0 or 1. When the problem is solved by the linear programming algorithm, the equation will define all variables as non-negative.

The consolidation terminal sites selection problem is thus formulated in the form of the 0 or 1 integer programming model. This formulation results from consideration of the characteristics of consolidation terminal site selection with regard to the design of the computer algorithm for problem solving. Detailed discussion of the computer algorithm for the model is presented in the next chapter on research design.
Conclusion

The consolidation terminal site selection model developed here has drawn much from the models presented in a previous section entitled "The Feasible Set Approach." The present model's formulation is the same as:

1. All the others in that it recognizes only a finite set of sources and destinations
2. All the others in that it recognizes both transportation and operating costs
3. All but the Efroymson-Ray model in that it makes operating costs the sum of a fixed charge component, plus a component which is a function of volume
4. The Baumol-Wolfe model in that it recognizes more than one type of shipment:
   - Consolidation Terminal $\rightarrow$ CBD zone
   - Consolidation Terminal $\rightarrow$ Truck Cluster
   - Consolidation Terminal $\rightarrow$ Consolidation Terminal
5. The Efroymson-Ray model in that it uses binary (0,1) variables in order to have more realistic (nonlinear) transportation and operating cost approximations.
CHAPTER III

RESEARCH DESIGN

The research design of this study involves parameter estimation and the development of heuristic procedures for making consolidation terminal site selections. The investigation into the number and location of consolidation terminals in Columbus, Ohio, requires the completion of the steps depicted in Figure 3-1, and outlined below:

1. Develop freight demand projections for the volume of freight which can be consolidated that enters and leaves the Columbus, Ohio CBD and for the volume which passes through the private and public truck operators
2. Identify and formulate the operating costs of the consolidation terminal
3. Determine the pickup and delivery costs from the consolidation terminals to the CBD
4. Determine the transportation costs from truck operator clusters to the consolidation terminals
5. Select and construct the computer algorithms to solve the integer linear programming model
Figure 3-1 Flow Chart of Research Steps
for the single terminal case and the discussion of the application of MPS/360 for the multiple terminal case.

6. Design a heuristic process for solving the linear integer programming of the consolidation terminal sites selection model

7. Define the model experiments

8. Test the number and locations of the consolidation terminal sites hypothesis through experiments with the heuristic solution procedure

9. Analyze the experiment results

10. Formulate conclusions and recommendations concerning the number and location of the consolidation terminal(s) and the economic desirability of a consolidation terminal system for Columbus, Ohio.

Steps one through seven are described in this chapter. Steps eight through ten will be presented in the next two chapters.

Projection of Pickup and Delivery Requirement in the CBD

The projection of pickup and delivery requirements in the CBD for the base year 1972 was constructed for this study from a cordon crossing study conducted in Columbus, Ohio, on November 16 & 17, 1972, by McDermott. The projection
takes into consideration an assessment of the floor space available for inventory in the CBD buildings, and also land use because the freight characteristics are dependent upon land use at either the origin or the destination of the shipment in the CBD.

The CBD is divided into ten zones for more efficient routing (Appendix B). Within each zone, four types of land use are classified: retail goods, retail service, office buildings, and industrial manufacturing firms. These zone and land-use classifications, as well as the quantity and weight of shipment, all bear directly upon the projection.

The projection also considers such factors as seasonality and the growth rate of the freight requirement. The seasonality factor is important because it affects the facility investment necessary to handle peak freight flows. This facility investment is part of the fixed cost of operating a consolidation terminal. The growth rate of the freight requirement is important also because the terminal system is a long-term investment and the planning horizon lasts for many years. Cadotte (1974), in his investigation of facility planning for the consolidation terminal, suggests a twelve-year planning horizon.

Regression methods have been utilized for estimating the growth rate for intercity freight. Morton (1973), Snow (1973), and a Battelle Memorial Institute Study (1974)
found a significant relationship between intercity freight tonnage volumes and the gross national product. Furthermore, Cadotte (1974) discovered that the multiplicative regression between the percentage increase of gross national product and the percentage increase of local freight during the period from 1962 to 1970 is:

\[ Y = 1.28946 \times 1.2884 \]

where \( Y \) = percentage increase in local freight, and \( X \) = percentage increase in gross national product

Future freight requirements, therefore, can be associated through this regression coefficient, with the gross national product growth rate for the 1970's projected by Faucett Associates, Inc., at the lower bound 3.5 percent, the most likely 4.3 percent, and the upper bound 5 percent (1973, pp. 2-4, 2-5).\(^1\) From this association, Cadotte estimates that the growth rate of local freight would be 3.96 percent, 4.86 percent, and 5.65 percent respectively (1974).

The projection of pickup and delivery requirements in the CBD is accomplished by combining the base year's pickup and delivery requirement with the three sets of growth rate (Table 3-1). This projection encompasses the aggregate freight

---

\(^1\)These estimates were made before the energy crisis and the subsequent worldwide inflation economy. Therefore, the predicted rate may be upwardly biased.
### TABLE 3-1

**PROJECTED DAILY SHIPMENT VOLUME**

**1974 - 1985**

<table>
<thead>
<tr>
<th>Year</th>
<th>Pessimistic Estimation</th>
<th>Most Likely Estimation</th>
<th>Optimistic Estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974</td>
<td>3183</td>
<td>3225</td>
<td>3263</td>
</tr>
<tr>
<td>1975</td>
<td>3318</td>
<td>3392</td>
<td>3458</td>
</tr>
<tr>
<td>1976</td>
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<td>3871</td>
</tr>
<tr>
<td>1978</td>
<td>3744</td>
<td>3929</td>
<td>4096</td>
</tr>
<tr>
<td>1979</td>
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<td>4125</td>
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</tr>
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<td>4545</td>
<td>4848</td>
</tr>
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<td>5258</td>
<td>5736</td>
</tr>
<tr>
<td>1985</td>
<td>4950</td>
<td>5520</td>
<td>6067</td>
</tr>
</tbody>
</table>
flow in the CBD. In order to determine the specific pick-up and delivery requirements within each zone of the CBD, this author used a report published by the Columbus Department of Development (September, 1973) in which the projected land use in the CBD is detailed for a twelve-year planning horizon.

Freight origin and destination in the CBD are expected to shift in accordance with a predicted gradual shift in the land-use mix. This, in turn, may affect consolidation terminal location, changing one year's ideal location into a location of decreased value and promise the next year. Thus, these possible shifts in freight demand were taken into consideration in the analysis.

For the Columbus study, the 1974 freight projections are used to evaluate the number and location of the consolidation terminal sites. The 1985 freight projection is considered in the final analysis in determining whether the shift in the land-use mix in the CBD has any impact on the terminal site(s) location.

**Forecast for the Freight Flow to and from Private and For-Hire Truck Operators**

Private and for-hire truck operators in the greater Columbus area are grouped into twelve clusters, based on
McDermott's cordon crossing survey taken on November 16 and 17, 1972 in Columbus. The total freight volume of the operators was equal to the total freight volume in the CBD. Thus, the growth rate and seasonality of the freight volume were identical to that of the freight destined to or originated from the CBD. The distribution of freight among the operator clusters was assumed to be constant through the planning horizon.

**Derivation of Cost Data for the Model**

The cost elements employed in the model consist of the cost of pickup and delivery between the consolidation terminal and the customer in the CBD, the transhipment cost between the truck operators' terminals and the consolidation terminal, the operating cost of the consolidation terminal, and, in the case of multiple consolidation terminals, the transhipment costs among these terminals. The cost function was stated in Equation [23] as follows:

\[
\text{Minimize } \sum_{i}^{m} a_{i} Y_{i} + \sum_{i}^{m} b_{i} S_{i} + \sum_{i}^{m} \sum_{j}^{n} c_{ij} X_{ij} \\
+ \sum_{i}^{m} \sum_{f}^{p} \sum_{d_{ij}}^{\text{dif}} Z_{ij} \\
+ \frac{1}{2} \sum_{k}^{\text{p}} \sum_{k}^{\text{l}} \sum_{j}^{\text{f}} e_{fklj} W_{fklj}
\]
Pickup and Delivery Cost Between the Consolidation Terminal and the CBD

The determination of pickup and delivery costs depends on two major factors: shipment characteristics, and the time required to make the stop. The second factor, in turn, is dependent on distance, routing, the condition of the traffic flow, and the queuing time at the dock. Although the shipment characteristics remain the same no matter where the consolidation terminal is located, the time required to make the stop depends on the location of the consolidation terminal relative to the CBD. This latter point serves as the basis for determining pickup and delivery costs.

The pickup and delivery cost is divided into two parts: part one is the cost of shipping from the consolidation terminal to the CBD zones, and part two is the cost of pickups and deliveries within each zone. Part one is the primary factor in determining terminal sites because once a truck enters a CBD zone, it will follow the same routing for pickups and deliveries and would thus incur the same costs under part two as for any other terminal location which served that particular zone.

The part one cost for each potential consolidation terminal site is determined as follows:
\[ c_{ij} = \left[ (T \times W/LD) \times \text{DAY} \right] \times MC \]

where

- \( c_{ij} \) = cost of pickup and delivery from designated consolidation terminal \( i \) to CBD zone \( j \);
- \( T \) = time required to travel (in minutes) from the designated terminal site to the CBD zone \( j \);
- \( W \) = total weight shipped (in pounds) from the designated terminal \( i \) to the CBD zone \( j \), or vice versa;
- \( MC \) = cost per minute of operating a freight truck;
- \( LD \) = average truckload weight in pounds by type of truck; and
- \( \text{DAY} \) = total number of working days in a year.

This cost function calculates the average yearly cost of pickup and delivery from the designated consolidation terminal to the CBD zone. Travel time requirements are derived by tracing the routing from the designated terminal to the CBD zone under normal traffic conditions. The total number of working days is assumed to be 250. The cost per minute of operating a freight truck has been determined by a national motor carrier to be thirty cents per minute.\(^1\) The

\(^1\)In order to protect the proprietary interests of the company, the carrier which provided the operating cost of the freight truck requested that it remain anonymous.
average carload weight is assumed to be 17,500 pounds.¹

Shipment Cost from Truck Operator Clusters to the Consolidation Terminal

The cost of shipment between the designated consolidation terminal and the truck operator clusters are derived from the following function:

\[
\text{\( d_{if} = \{ [T \times (W/LD) \times F] \times \text{DAY} \} \times \text{MC} \)}
\]

where

\( d_{if} \) = shipment cost from truck operator cluster \( f \) to consolidation terminal \( i \);

\( F \) = fraction of a truckload serving as an adjustment factor; and

\( T, W, LD, MC, \) and \( \text{DAY} \) are the same as defined in the previous section.

The derivation of this shipment cost is similar to that of the shipment cost to the CBD. The only difference is the fraction of a truckload adjustment factor. This adjustment is necessary for those situations in which the truck operator does not have a full truckload of small shipments destined to or originated from the CBD. It is also necessary for those situations in which the truck operator makes

¹This corresponds to the average weightload of a fully loaded 28-foot semi-tractor trailer.
stops at the consolidation terminal while he is shipping freight en route for other shipments. The fraction adjustment factor ranges from the actual fraction (i.e., the volume of small shipments destined to or originated from the CBD divided by the truckload volume) to 1 (i.e., whole truckload). The fraction adjustment is assumed to be .75, on the average.

**Operating Cost of the Consolidation Terminal**

The operating cost of the consolidation terminal is determined by four factors: rent, facility investment, overhead, and the volume processed. The rent covers both the land and the building being operated as a consolidation terminal.

**Size of the Terminal and Its Land Cost**

Cadotte estimates that a consolidation terminal with a towveyor system would require a 440-foot length and 226-foot width to handle 4,500 shipments per day totaling about 550 tons, and would also require 100 doors for loading and unloading (1974). The total constructed area, using Cadotte's estimations, would be about 90,000 square feet, which is slightly over two acres. The terminal handbook prepared by Davies (p. 5, 1966) recommends that a modern terminal with safe and easily accessible entrances and exits and sufficient operating and parking grounds for trucks
requires open land area three to six times the size of the building. On that scale, a consolidation terminal would occupy a total land area of approximately ten acres.

In his study of facility design, (1974) Cadotte also investigated four different material handling systems; tilt-slanit sorting conveyor, towveyor with non-powered bump-off spurs, towveyor without spurs, and a simple manual four-wheel cart system. Each of these systems requires a different amount of investment and a different level of manpower for operation. Their relative costs are related to the number of shipments, as shown in Figure 3-2.

In addition to land acquisition and facility equipment as factors constituting the fixed investment, there is the construction of the terminal itself. Estimates of the ability of various terminal sizes to house different facilities are provided by Cadotte's study (1974).

All these investments -- land acquisition, terminal construction, and facility setup -- are long-term investments whose annual operating costs can be obtained by using the equivalent annual cost principle. This principle allows the original investment, minus the present worth of its salvage value, to be converted into an equivalent series of equal end-of-period payments.

The weighted average cost of capital for the trucking industry has been estimated by Cadotte (1974) at 7.8 percent
Source: Cadotte, 1974.

Figure 3 - 2
from 1960 to 1972. However, market conditions for cost
equity in mid-1974 were quite different from those of
previous years: the unweighted average cost as of July 12,
1974, was 19.71 percent (Wall Street Journal, July 15, 1974).1
Nevertheless, the high cost of equity in the first half of
1974 is expected to come down (Wall Street Journal,
Toldessy, July 22, 1974, p. 4). According to an industry-
based source, the average cost of a long-term loan from an
insurance company or a pension fund was about ten to eleven
percent as of July, 1974.2 Therefore, for the purposes of
this study, and in view of historical trends and the recent
development of long-term weighted average costs of equity
for the money market, the cost of capital is assumed to be
ten percent.

The operating cost function is expressed as follows:

\[ \sum_{i=1}^{m} C_i = \sum_{i=1}^{m} a_i Y_i + \sum_{i=1}^{m} b_i S_i \]

where

\[ a_i = .12 \times L_{C_i} + .115 \times (F_{TC_i} + FMC) \]
\[ b_i = .115 \times (V_{TC_i} + VMC) + MANC \]

1For truck carriers listed in the New York and American
Stock Exchanges, and which Transport Topics includes in
their general commodities carrier index.

2Hank Lishied, partner in the commercial and industrial
real estate brokerage and development firm, Lee Wears, Inc.,
Columbus, Ohio, interviewed on July 15, 1974.
thus

\[ \bar{\mathcal{C}}_i = 0.12 \times LC_i + 0.115 \times (FTC_i + FMC) \]

\[ + [0.115 \times (VTC_i + VMC) + MANC] \times S_i \]

where

\[ \bar{\mathcal{C}}_i \] = operating cost of the consolidation terminal \( Y_i \);

\[ S_i \] = total volume of shipment process at terminal \( i \);

\[ LC_i \] = land acquisition cost at site \( i \);

\[ FTC_i \] = fixed cost of the terminal building at site \( i \);

\[ VTC_i \] = variable cost of the terminal building at site \( i \);

\[ FMC \] = fixed cost of material handling system;

\[ VMC \] = variable cost of material handling system;

and

\[ MANC \] = variable cost of manpower for the consolidation terminal.

A discount rate of ten percent is used in the derivation of operating cost, but two percent is added to the land cost as an estimate of the tax per year on the land. To the terminal building and facility setup costs, 1.5 percent is added to cover their annual maintenance costs, as specified by Cadotte's study (1974).
Transhipment Cost

Transhipment in a multiple consolidation system is a shipment from one consolidation terminal to another, occurring when a truck cluster served by one consolidation terminal receives a shipment destined to a CBD zone served by another consolidation terminal. For instance, transhipment variable \( W_{fk\ell j} \) indicates that the shipment is originated from or destined to truck cluster \( f \), which is served by consolidation terminal \( k \), and is then transhipped to consolidation terminal \( \ell (k = \ell) \) in order to be delivered to (or to be picked up from) CBD zone \( j \). The cost of transhipment is determined by the transportation cost required to ship \( k \) to \( \ell \) and the second sorting required at terminal \( \ell \).

Therefore, the transhipment cost is expressed as follows:

\[
e_{fk\ell j} = [ (T \times W/\text{LD}) \times \text{DAY} ] \times \text{MC} + \text{ST}
\]

where

\[
e_{fk\ell j} = \text{the transhipment cost of the shipment } W_{fk\ell j};
\]

\[
\text{ST} = \text{the cost of the second sorting of the shipment } W_{fk\ell j};
\]

\( T, W, \text{LD, DAY, and MC} \) are the same as defined in the previous section.

By combining the fixed and variable costs of the terminal operating cost, the total system cost of the
consolidation terminal system becomes as follows:

\[
\sum_{i} (\bar{C}_i) Y_i + \sum_{i} \sum_{j} c_{ij} X_{ij} + \sum_{i} \sum_{f} d_{if} Z_{if} + \frac{1}{2} \sum_{f} \sum_{k} \sum_{l} e_{fkl} W_{fklj}
\]

Construction of a Computer Algorithm

The consolidation terminal site selection model, as developed in Chapter II, is formulated as a nonlinear integer programming problem. Since there is no general method for computing the optimum values of the variables of such a problem, the Baumol-Wolfe approach is adopted to heuristically solve nonlinear programming. The heuristic solution design is discussed in the next section. The focus here is the development of a computer algorithm for solving linear integer programming.

In order to develop an algorithm which solves the integer programming problem without explicitly enumerating all the possibilities, the algorithm should partially enumerate a manageable of possibilities and implicitly enumerate all the rest. Beale (1968) pointed out four distinct approaches to solving the integer problems; cutting plane, branch and bound, partial enumeration, and primal.

Cutting plane algorithms have not been found to be
uniformly successful. In particular, they have not worked well with combinatorial problems (Wagner, 1969). Furthermore, the number of iterations required to obtain a solution seems to depend considerably on the specific formulation of the problem.

Branch and bound methods work well in problems containing a few integer-valued variables. But if the number of variables is large, or if the linear programming solution to the problem is far from optimal, giving poor estimates of bounds, then the number of iterations may be too large for the practical application of the algorithm (Wagner, 1969). Also, the branch and bound algorithm requires a large amount of storage for all the eligible nonterminal nodes and associated information, and, therefore, makes necessary the designing of a way to solve large problems in stages.

The computer algorithm adopted for this research study is the one developed by Samsao Woiler in his Implicit Enumeration Algorithms for Discrete Optimization Problems (1967). This algorithm is an approach to solving the pure integer programming model with 0-1 decision variables. The algorithm, originally written in ALGOL, is constructed in FORTRAN IV for this study.\textsuperscript{1} It is very efficient when the

\textsuperscript{1}This author received help from his colleague, Edward Blakely, of Wright State University, in preparing the FORTRAN IV programming of the 0-1 integer programming.
problem size is small: a problem with less than thirty binary variables was solved in less than twenty-seven seconds (Woiler, 1967, p. 110). When applied to the single consolidation terminal site selection model with eighty constraints and one-hundred and sixty-one variables, the algorithm takes only thirty-eight seconds to reach an optimal solution. However, in the case of multiple consolidation terminals, it takes much longer. Therefore, the primal method must be considered in the multiple terminal case.

The consolidation terminal sites selection model developed in Chapter II is here revised in order to utilize linear programming package such as IBM's MPS/360. Note that transhipment term \( \frac{1}{2} \sum \sum \sum e_{fj} W_{fk} \) in Equation [23], in the multiple terminal case, involves thousands of variables. For instance, when \( i = 6 \), \( f = 12 \), and \( j = 10 \), there are 3600 variables of \( W_{fk} \). Consequently, there are 36000 constraints in Equation [30] alone. Furthermore, when the problem is solved as a linear programming problem in order to minimize the system cost, the variable \( W_{fk} \) in the equation \( Z_{kf} + X_{kj} - W_{fk} = 1 \) is often forced into 0, while \( Z_{kf} + X_{kj} \) becomes 1. Thus, \( Z_{kf} \) and \( X_{kj} \) will take fractional values which are not desirable for the model. Therefore, the transhipment requirements in the model are
removed during the MPS/360 computer runs and are reconsidered later in the heuristic solution procedure in the next section.

When the consolidation terminal sites selection model is run on MPS/360 in this manner, all but the $Y_i$ variables will result in 0 or 1. As Weingartner (1960) pointed out, the ranking of the $Y_i$ variables can be achieved by examining the primal and dual values of respective $Y_i$'s. By forcing more attractive (high-ranking) $Y_i$ variables into 1, and less attractive to 0, the problem can be solved within forty seconds on an IBM 360/165 computer for the multiple consolidation terminal case.

**Heuristic Design for the Optimization of Multiple Terminal Case**

The consolidation terminal sites selection model is designed as a linear integer model. In the single terminal case, the problem can be constructed as a combinational optimization problem and solved by the Koeber algorithm. In this algorithm the nonlinear operating cost can be determined at the full capacity of each of the candidate terminal sites. The solution generated from the Koeber algorithm will be an optimal one.

In the multiple terminal case, two types of problems
must be contended with: integer solutions and the nonlinear cost function. Baumol-Wolfe (1958) have shown that the nonlinear objective function can be successfully dealt with by applying the iterative procedure heuristically. In the study, a heuristic design is developed to solve these problems. In order to utilize the heuristic procedure, the consolidation terminal selection model is revised to generate an initial solution from the following formulation:

Minimize

\[
\sum_{i} \left( \sum_{i} C_{ij} X_{ij} + \sum_{i} \sum_{f} d_{if} Z_{if} \right)
\]

Subject to

\[
\sum_{i} X_{ij} = 1 \quad j = 1, 2, \ldots, n
\]

\[
\sum_{i} Z_{if} = 1, \quad f = 1, 2, \ldots, p
\]

\[
\sum_{i} Y_{i} = t,
\]

\[
\sum_{f} Z_{if} + \sum_{j} X_{ij} \leq u Y_{i}, \quad i = 1, 2, \ldots, m
\]

\[
\sum_{f} Z_{if} \geq v Y_{i}, \quad i = 1, 2, \ldots, m
\]

\[
\sum_{j} X_{ij} \geq r Y_{i}, \quad i = 1, 2, \ldots, m
\]

\[
Y_{i} \leq 1, \quad i = 1, 2, \ldots, m
\]

\[
Y_{i}, X_{ij}, Z_{if} \geq 0 \quad \text{all } i, j, \text{ and } f
\]
The flow chart for this design is shown in Figure 3-3 and is described as follows:

**Step 1:**
Set up a linear programming problem consisting of Equation [34] to Equation [42]. In this formulation the transhipment requirements term $W_{fklj}$ is dropped from Equation [23]. The operating cost ($OC_i$) derived at a predetermined level of $S_i$, which is set at the expected maximum freight flow at each candidate terminal.\(^1\) Initialize the parameters $t$, $u$, $v$, and $r$.

**Step 2:**
Solve the linear programming problem by MPS/360. The variables $X_{ij}$ and $Z_{if}$ will be in the form of $(0, 1)$. However, the $Y_i$ variables may contain fractional values.

**Step 3:**
Create a list of $s$ locations, consisting of all locations with non-zero $Y_i$ values plus the location with a zero value which has the smallest dual value. This step selects from the set of all candidate sites a subset to be considered for

---

\(^1\)Although some terminals may operate at a smaller capacity scale due to the transhipment requirement, the actual volume processed will not deviate too much from the expected maximum volume.
A Heuristic Solution For

Consolidation Terminal Sites Selection Model

Start

Set up LP model consists of Eq. (42) - Eq. (44)
\[ S_t \] at expected maximum volume.
Initialize \( t, u, r, \) and \( v. \)

Solve LP by "PS/3ni"

Create list of \( s \) locations - all \( Y_s \geq 0 \) and one \( Y_s = 0 \) with lowest dual value

Create all \( n \) possible combinations of the \( s \) locations, where
\[ Y_s = \begin{cases} 0, & \text{if } l \neq q_s, \\ 1, & \text{if } l = q_s \end{cases} \]
and
\[ c_m = \frac{s!}{t!(s-t)!} \]

Select one set out of \( n \) sets sequentially

Update LP model: calculate \( C_1 \) based on \( q \), adjust \( C_{ij} \) and \( D_{ij} \) for the transhipment cost

Solve LP by "PS/3ni"

Does any \( DC_{x,y}, h_i, \) or \( C_{ij} \) change?
Yes: \( k = k + 1 \)

No

List all solutions

Compare all solutions and select the least cost solution

Print the solution

End

Figure 3-3
the most attractive for the multiple consolidation terminal. If there are only a few candidate sites \((Y_i)\) for the consolidation terminal, it may not involve too much effort to consider all the \(Y_i\) variables. However, if the number of \(Y_i\) variables with nonzero values is large, it may be necessary to limit the subset to a manageable size. An effective heuristic rule, in this case, is to select the \(Y_i\) which has the higher value and which also has a large number of corresponding \(X_{ij}\) and \(Z_{if}\) having nonzero values.

**Step 4:**

Create \(m\) possible combinations of the \(s\) locations, taken \(t\) at a time. Although the total number of combinations is at

\[
m = \frac{s!}{t! (s - t)!}
\]

the actual combinations will be less than the maximum number. Let each combination be denoted as \(\phi_q\), which always includes the element \(Y_i\) when \(Y_i\) is 1 in the MPS solution. For instance, when \(s = 5\) and \(t = 2\), there will be ten possible combinations

\[
m = \frac{5!}{2! 3!} = 10
\]
But if one of the \( Y_i \) is 1, then the total number of combinations will be reduced to 4, because each combination will include the \( Y_i \) (\( Y_i = 1 \)), thus effectively reducing the number of possible combinations. For instance, when \( i = 6 \) and \( t = 2 \), one of the \( Y_i = 1 \). Even though all the other \( Y_i \) are in the subset, the total combinations will be five sets only.

**Step 5:**

Set counter \( q = 0 \).

**Step 6:**

Select one set of solution combinations from the \( m \) sets created in Step 4, sequentially.

**Step 7:**

Set counter \( q = q + 1 \).

**Step 8:**

Set counter \( k = 1 \).

**Step 9:**

Update linear programming problem.

(a) Set \( Y_i \) value, where

\[
Y_i = \begin{cases} 
0, & \text{if } i \notin 0_{qi} \\
1, & \text{if } i \in 0_{qi}
\end{cases}
\]

(b) Determine \( S_i \) and cost coefficients of \( UC_i \), \( c_{ij} \) and \( d_{ij} \) in the linear programming. The
cost coefficients are derived from actual volume processed through each "open" terminal for previous LP solution. The adjustments of $c_{ij}$ and $d_{ik}$ are related to the transhipment situation. The transhipment requirements are dropped from the problem formulation for the initial MPS run. Therefore, in order to account for the transhipment requirements in the consolidation site selection decision, the transhipment requirements are brought back into this step. A transhipment is required whenever the consolidation terminal serving the CBD zone does not serve the truck operator clusters where the freight is coming from or destined to. $c_{ij}$ was initially defined as the cost of shipping all volume from terminal $i$ to CBD zone $j$. Now, $c_{ij}$ is adjusted with one-half the cost which results the portion of the volume that is transhipped from another terminal $k$ to the terminal $i$. The new $c'_{ij}$ is expressed as follows:

$$c'_{ij} = c_{ij} + \frac{1}{2} \left[ TS_{ik} \times VOS \right]$$

where $TS_{ik} =$ per unit cost of transhipment, $VOS =$ volume transshipped.

The other half of the transhipment cost is
accounted to $D_{kf}$; that is

$$D'_{kf} = D_{kf} + 1/2 \left[ TS_{ik} \times VOS \right].$$

**Step 10:**
Solve the updated linear programming problem by MPS/360.

**Step 11:**
Compare the values of $\overline{OC}_i$, $X_{ij}$ and $Z_{if}$ from the new solution with the $(K - 1)$ iteration. If there is no change in any of the $\overline{OC}_i$, $X_{ij}$, or $Z_{if}$ values, solution has been reached. Exit to **Step 14**. Otherwise, go to **Step 12**.

**Step 12:**
Set counter $K = K + 1$.

**Step 13:**
Compare $K$ to parameter $\alpha$, if convergence of the solution is very slow. $\alpha$ is set to direct the heuristic rule to bypass the problem whenever $k$ is greater than $\alpha$. Otherwise, go back to **Step 9**.

**Step 14:**
Check whether all the $m$ sets have been evaluated. If they have been, go to **Step 15**. Otherwise, go to **Step 6**.

**Step 15:**
List $m$ sets of solutions.
Step 16:
Compare m sets of solutions, and select the least cost solution set from them.

Step 17:
Write out the solution. End the heuristic procedure.

This heuristic procedure converges in a few iterations, because the operating cost contains a heavy setup cost. Thus, the operating cost generated is not very sensitive to the volume processed (Table 3-2). In the Columbus case, the final solution of the multiple consolidation terminal site selection was always reached in two iterations (k = 2).

Formulation of Alternative Consolidation Terminal Sites

The formulation of alternative consolidation terminal sites is based on three factors: easy access to the CBD or to the trucker clusters, industrial development zoning, and land availability. The access factor considers placement on or adjacent to a major highway artery (either inner belt, outer belt, or through highway) of a metropolitan area. Zoning and land availability reduce alternative sites considerably, since a consolidation terminal performs a special function of industrial service and must occupy a large land
<table>
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<tr>
<th>MATERIAL MANAGING SYSTEM</th>
<th>VOLUME PROCESS</th>
<th>SHIPMENTS</th>
<th>SITE 1</th>
<th>SITE 2</th>
<th>SITE 3</th>
<th>SITE 4</th>
<th>SITE 5</th>
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<td>90216.48</td>
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area.

Assistance in formulating the alternative sites for the Columbus study came from an interview with Mr. Hank Lishied, a partner in the commercial and industrial real estate brokerage and development firm, Lee Wears, Inc., which took place on July 10, 1974. Mr. Lishied recommended seven sites for consideration. Because further investigation indicated that one of these sites was not available for terminal purposes, only six alternative sites were formulated for the study (Figure 3 - 4).

None of the six sites are within the CBD. Although an examination of an alternative site within the CBD was originally planned, the consolidation terminal's large land-area requirements preclude the possibility of such a location. Also, high land values in the CBD make the site economically infeasible. Furthermore, a terminal in the CBD would tend to defeat its prime objective of reducing freight traffic in the CBD, if truck operators are allowed to pickup and deliver their shipments to the consolidation terminal within the CBD. To circumvent this last difficulty requires considerable effort to coordinate and schedule pickups and deliveries at truck operators' terminals and also requires a tremendously increased capital investment. Therefore, no alternative sites within the CBD have been selected.

Lishied also provided cost estimates of the land value
Figure 3-4. Map of six alternative consolidation terminal sites in Columbus.
for each alternative terminal site (Table C - 1). These land costs are incorporated into the computer program to generate the operating cost of the alternative consolidation terminals.

Assumption of the Study

In order to undertake the research study and utilize the preceding mathematical model and the heuristic procedure as a research tool, the following assumptions were introduced. It was assumed that

1. There was no capacity limitation on the consolidation terminals.

2. Each alternative site had the same type of facility when the volume processed was the same (the difference in the terminal operating costs was attributed to land cost, tax structure, and scale of terminal).

3. The delivery and pickup to and from the CBD was scheduled by the consolidation terminal. A twenty-four hour service standard was assumed. Shipments received by 11:00 A. M. were to be delivered in the same day. Shipments received after 11:00 A. M. were to be delivered in the following working day.
4. Delivery and pickup trucks based at the terminal were assumed to leave at 9:00 A. M. for the CBD and return randomly around 3:00 P. M.

5. A 250-day per year operation was in effect.

Model Experimentation

The mathematical model and the heuristic procedure depicting the interrelationships between demand locations in the CBD, trucker clusters, routings, terminal locations, terminal operating scale, and the system cost function served as the primary research tool for the study. First, the experimental approach was to employ the model to obtain contrasting sets of experimental conditions which were indicated by each null hypothesis. Second, it compared the costs obtained from the model to determine if the null hypothesis in question should be rejected.

Experiment 1 \((H_0-1)\)

Select the comparison sets, single versus two terminals, single versus three terminals, and single versus four terminals, all terminals being located in the suburbs, to determine the impact of multiple terminals on the system costs.

The experiment requires the structuring of fixed investment requirements, as well as the variable operating
cost by scale for the terminals.

**Experiment 2 (H₀-2)**

Select the least system cost location near the CBD and the least cost system cost location in the suburbs for the comparison. The experiment is to examine the economic feasibility of the location near the CBD in contrast to the suburban location. With the data from this experiment and the last experiment (Experiment 1), the Hypothesis 3 (H₀-3) can be examined without requiring any further experiment.

**Experiment 3 (H₀-4)**

The heuristic mathematical model is altered to select a least system cost location, based on 5,000 pounds shipment size, to be compared with the least system cost location selected in the previous experiments. The objective of the comparison is to provide insight into the shipment size change on terminal location decisions.

**Experiment 4 (H₀-5)**

The locations of demand requirements will be altered for this experiment to examine the impact of shift of demands on the terminal locations. The experiment concerns itself with the terminal(s) chosen from the previous experiments. The experiment's emphasis is placed on the
trend of carriers' terminal locations, as well as growth and shift demand in the CBD.

Each of the above experiments requires consideration of fixed investment and their expected discount rate of cost of capital for the derivation of total system costs. The selection of specific fixed investments and the discount rate of cost of capital were outlined earlier in the chapter.

Analysis of Results

The heuristic mathematical model is, as stated earlier, a deterministic model. Consequently, the analysis requires one heuristic solution for each experimental condition to be investigated. In addition, the deterministic method of analysis suggests there will be no need for any specific statistical test. However, in order to establish a criterion for the acceptance or rejection of the null hypotheses, it is proposed that the hypotheses be rejected if the variation between the least cost alternative and all other alternatives is more than five percent of the lower cost alternative. In this manner, the study will determine the most effective low-cost plan for the number and location of terminals in the urban consolidation terminal system.
CHAPTER IV
RESEARCH FINDINGS

This chapter presents the research findings from the model experiments, which concern the economic system costs of the consolidation terminal with regard to the number and location of the terminals(s). The number of terminals under study range from one to four; the locations range from the CBD vicinity to the outerbelt areas. The chief method of evaluating the model experiments is the heuristic solution of the site selection models.

In the previous chapters the hypotheses and model experiments are defined. In this chapter the contrasting conditions of each experiment are identified, and their respective system costs are then derived from the heuristic solution. Next, the system costs of the contrasting heuristic solutions are compared with the criteria specified in the related hypothesis. Based on this comparison, the hypothesis is either accepted or rejected.

Experiment 1 (H₀ - 1)
In experiment 1 there are three comparison sets: single versus two, single versus three, or single versus four terminals, all terminals being located in the suburbs.
Figure 4-1. Map of twelve truck clusters and six alternative consolidation terminal sites in Columbus, Ohio.
Figure 4-2. Map of the Columbus, Ohio CBD: ten zones.
The heuristic solution of the computer model is set to program each of the contrasting conditions of the comparison sets. According to hypothesis Ho-1, the null hypothesis should be accepted if the system cost of the consolidation terminal does not vary more than five percent from the lower cost alternative.

The location and sizing of consolidation terminals from each comparison set are presented in Tables D-1 through D-4 in Appendix D. The total system costs are summarized in Table 4-1. Comparison of the system costs can be made on two levels. One level is the cost derived from this study, which includes terminal operating cost, the shipment costs between the consolidation terminal and the truck clusters, and the shipment costs between the consolidation terminal and the CBD. At this level (see Column 5 of Table 4-1) the comparison reveals a significant 28.7 percent difference between the single terminal and the two-terminal system. On the total system cost level, which includes the sum of the above cost and the pickup and delivery cost in the CBD (see Column 7 of Table 4-1), there is a 5.1 percent difference between the single terminal and the two-terminal system. Although this figure is beyond the allowance of the threshold five percent level, it is close enough to suggest some further qualitative considerations which the model ignores.
### TABLE 4 - 1

**COMPARISONS OF SYSTEM COSTS UNDER SINGLE CONSOLIDATION TERMINAL VERSUS MULTIPLE TERMINAL ALL IN THE OUTERBELT AREA**

<table>
<thead>
<tr>
<th>Number of Terminals (1)</th>
<th>Location Site (2)</th>
<th>Zones Servedb (3)</th>
<th>Clusters Served G (4)</th>
<th>System Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Operating &amp; Shipment (5)</td>
</tr>
<tr>
<td>Single</td>
<td>6</td>
<td>1,2,3,4,5,6,7,8,9,10</td>
<td>1,2,3,4,5,6,7,8,9,10,11,12</td>
<td>253,669</td>
</tr>
<tr>
<td>Two</td>
<td>2</td>
<td>7</td>
<td>1,10</td>
<td>326,483</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1,2,3,4,5,6,7,8,9,10</td>
<td>1,2,3,4,5,6,7,8,9,10,11,12</td>
<td>415,563</td>
</tr>
<tr>
<td>Three</td>
<td>1</td>
<td>7</td>
<td>8</td>
<td>469,995</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>9</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1,2,3,4,5,6,8,10</td>
<td>1,2,3,4,5,6,7,8,9,10,11,12</td>
<td>1,165,500</td>
</tr>
<tr>
<td>Four</td>
<td>1</td>
<td>7</td>
<td>8</td>
<td>415,563</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>9</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1,2,3,4,6,8,10</td>
<td>1,2,3,4,5,6,7,9,10,11,12</td>
<td>253,669</td>
</tr>
</tbody>
</table>

aSee Figure 3-4 or Figure 4-1
bSee Figure 4-2
cSee Figure B-2 or Figure 4-1
Experiment 2 (Ho-2)

In experiment 2, two contrasting single terminal cases are under study: the first terminal (in the suburb) is derived from experiment 1, and the other (near the CBD) is then derived from the heuristic solution and shown in Table D-5. The total system costs of these two contrasting alternatives are summarized in Table 4-2.

A comparison of the operating and shipment costs of a single terminal near the CBD versus a single terminal in the suburban outerbelt area (see Table 4-2, Column 5) reveals the the cost differential is 13.6 percent, which is beyond the five percent allowance. But the total system cost, which includes the above cost plus the pickup and delivery cost within the CBD zones, shows a 1.5 percent difference, which is significant. The reason for this is that the pickup and delivery cost within the CBD, which makes up about eighty percent of the total system cost, is the same for any terminal location. Therefore, the total system cost is to an extent insensitive to the locality of the terminal. In view of these factors, the null hypothesis Ho-2 is accepted.

With data from experiments 1 and 2, three contrasting sets of comparisons can be derived: single downtown terminal versus two, three and four outerbelt terminals. The total system costs of these contrasting alternatives are
# TABLE 4 - 2

**COMPARISON OF SYSTEM COSTS UNDER SINGLE CBD VICINITY TERMINAL VERSUS SINGLE OUTERBELT**

<table>
<thead>
<tr>
<th>Number of Terminals</th>
<th>Location Site</th>
<th>Zones Served</th>
<th>Clusters Served</th>
<th>System Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Operating &amp; Shipment</td>
</tr>
<tr>
<td>Single Outer-belt</td>
<td>6</td>
<td>1,2,3,4,5,6, 7,8,9,10</td>
<td>1,2,3,4,5,6,7, 8,9,10,11,12</td>
<td>253,669</td>
</tr>
<tr>
<td>Single CBD Vicinity</td>
<td>5</td>
<td>1,2,3,4,5,6, 7,8,9,10</td>
<td>1,2,3,4,5,6,7, 8,9,10,11,12</td>
<td>232,094</td>
</tr>
</tbody>
</table>

*a* See Figure 3-4 or Figure 4-1  
*b* See Figure 4-2  
*c* See Figure B-2 or Figure 4-1
summarized in Table 4-3. The cost differential of the single downtown terminal versus any of the multiple outer-belt terminals is beyond the five percent variance allowance. Therefore, the null hypothesis Ho-3 is rejected.

Experiment 3 (Ho-4)

In experiment 3 the study focuses on shipment sizes up to 5,000 pounds. The least cost system, derived from previous experiments, is compared with least cost systems in which the shipment size is 5,000 pounds instead of 1,000 pounds. These results are presented in Tables D-6 through D-10. Comparisons of the system costs of the various terminal alternatives indicate that costs are higher for freight up to 5,000 pounds than for freight up to 1,000 pounds. However, least cost solutions are identical for both 5,000-pound and 1,000-pound shipment sizes, and thus terminal site selection is not affected by changes in maximum shipment size. Nevertheless, from the economic benefit standpoint, the trade-off of incremental cost and savings from including freight up to 5,000 pounds (Table 4-4) do not warrant the inclusion of these larger shipment sizes. Therefore, the null hypothesis Ho-4 is rejected.
<table>
<thead>
<tr>
<th>Number of Terminals (1)</th>
<th>Location Site (2)</th>
<th>Zones Served (3)</th>
<th>Clusters Served (4)</th>
<th>System Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Operating &amp; Shipment (5)</td>
</tr>
<tr>
<td>Single CBD</td>
<td>5</td>
<td>1,2,3,4,5,6,7,8,9,10</td>
<td>1,2,3,4,5,6,7,8,9,10</td>
<td>232,094</td>
</tr>
<tr>
<td>Multiple Outer-belt</td>
<td></td>
<td></td>
<td></td>
<td>326,483</td>
</tr>
<tr>
<td>Two</td>
<td>2</td>
<td>1,2,3,4,5,6,7,8,9,10</td>
<td>1,2,3,4,5,6,7,8,9,10</td>
<td>415,563</td>
</tr>
<tr>
<td>Three</td>
<td>1</td>
<td>1,2,3,4,5,6,7,8,9,10</td>
<td>1,2,3,4,5,6,7,8,9,10</td>
<td>469,905</td>
</tr>
</tbody>
</table>

*See Figure 3-4 or Figure 4-1

*bSee Figure 4-2

cSee Figure B-2 or Figure 4-1
### TABLE 4 - 4

**COMPARISON OF ECONOMIC SAVINGS OF CONSOLIDATION**

**SHIPMENT SIZES UNDER 5,000 POUNDS VERSUS SHIPMENT SIZES UNDER 1,000 POUNDS**

<table>
<thead>
<tr>
<th>Number of Terminals</th>
<th>Location Site</th>
<th>Zones Served</th>
<th>Clusters Served</th>
<th>Operating &amp; Shipment</th>
<th>Pickup &amp; Delivery</th>
<th>Total</th>
<th>Incremental Cost</th>
<th>Incremental Savings</th>
<th>Net Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single</td>
<td>5</td>
<td>1, 2, 3, 4, 5, 6, 7, 8, 9, 10</td>
<td>1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12</td>
<td>249,697</td>
<td>1,638,000</td>
<td>1,881,697</td>
<td>484,103</td>
<td>611,000</td>
<td>125,897</td>
</tr>
<tr>
<td>Single</td>
<td>6</td>
<td>1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12</td>
<td>1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12</td>
<td>266,657</td>
<td>1,638,000</td>
<td>1,904,657</td>
<td>485,488</td>
<td>611,000</td>
<td>125,512</td>
</tr>
</tbody>
</table>

*See Figure 3 - 4 or Figure 4 - 1
b See Figure 4 - 2
c See Figure B - 2 or Figure 4 - 1
Experiment 4 \((Ho-5)\)

In experiment 4 the cost of transhipment from the trucker clusters to each of the potential consolidation terminal sites is assumed to be zero. This assumption serves two purposes: first, it provides insight into the case in which the cost of shipment from the trucker clusters is borne by the truck operators themselves, and the effect of this on the location of the consolidation terminal. Second, it considers the case in which truck operators may eventually cluster around the consolidation terminal(s), and thus make transhipment costs between them insignificant.

The system costs of each alternative are generated from the heuristic computer solution by altering the shipment costs from previous runs. The results are presented in Tables D-11 through D-15. The system costs are summarized in Table 4-5. The least cost terminal site is the same as the one selected in experiment 2. Therefore, the null hypothesis \(Ho-5\) is accepted.

Other Findings

The investigation into the economic feasibility of an urban consolidation terminal or terminals for Columbus, Ohio requires the identification and estimation of the cost trade-offs between various numbers, locations, and sizes of the terminal site selection model. In the course of this
### TABLE 4 - 5
COMPARISONS OF SYSTEM COSTS WHEN TRANSPORTATION COSTS BETWEEN
CLUSTERS AND THE TERMINAL ASSUMED TO BE MINIMUM

<table>
<thead>
<tr>
<th>Number of Terminals</th>
<th>Location Site a</th>
<th>Zones Served b</th>
<th>Clusters Served c</th>
<th>System Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single</td>
<td>5</td>
<td>1,2,3,4,5, 6,7,8,9,10</td>
<td>1,2,3,4,5, 6,7,8,9,10,11,12</td>
<td>99,542 1,165,500 1,265,042</td>
</tr>
<tr>
<td>Single</td>
<td>6</td>
<td>1,2,3,4,5, 6,7,8,9,10</td>
<td>1,2,3,4,5, 6,7,8,9,10,11,12</td>
<td>135,025 1,165,500 1,300,525</td>
</tr>
</tbody>
</table>

aSee Figure 3-4 or Figure 4-1
bSee Figure 4-2
cSee Figure B-2 or Figure 4-1
study, it has been observed that a single terminal can provide a better service than a multiple terminal. A single terminal requires only one sorting process for shipments, while a multiple terminal may require double sorting at two different consolidation terminals. The latter case is true when one consolidation terminal picks up shipments from a trucker cluster which are destined to CBD zones served by other consolidation terminals, or when a consolidation terminal picks up shipments from its own CBD zone which are destined to trucker clusters served by other consolidation terminals. Under any of such circumstances, a transhipment among consolidation terminals is called for, thus requiring double sorting and more service time at each related terminal.

**Summary**

The objective of this chapter has been to present the findings of the four experiments concerning the number and location of the terminal site selection model. Hypothesis Ho-1, Ho-3, and Ho-4 have been rejected, while hypothesis Ho-2 and Ho-5 have been accepted. Also discussed is the impact of the terminal number on the service rate. Specific conclusions concerning the above findings will be drawn in the next chapter, and the implications of the total study will be explored.
CHAPTER V

SUMMARY AND CONCLUSION

This chapter will present, in five sections, a comprehensive discussion of the research study. The first section restates the purpose and methodology of the study and summarizes its findings. The second section presents the conclusions of the study, based on findings from the research hypotheses and other sources. The third section reviews the study's implications for the economic feasibility of the consolidation terminal in general, and for terminal allocation in particular. Suggestions for further research and a chapter summary follow.

**Brief Statement of the Problem**

The present system for pickup and delivery of small shipments within an urban center is a relatively inefficient one. The basic problems arise from the fact that the urban center is too small an area to accommodate the exceedingly large number of trucks and truck operators which serve the area. Such a surfeit of uncoordinated truck activity leads to route duplication, street congestion, long waits at loading/unloading facilities, and under-
utilization of truck capacity. The increased cost which results must be borne by the shippers, consignees, and the public, while the latter additionally suffers the consequences of traffic congestion, pollution, energy consumption, and higher costs. The most promising alternatives to the present system appear to be temporal separation, spatial separation, required off-street loading/unloading facilities, traffic engineering, and consolidation terminals. This last alternative was selected as the focus of this study. Potential roadblocks to the implementation of the consolidation terminal system, or any of the other alternatives, are the absence of mechanisms necessary for a total system change and the truck operators' possible fear of relinquishing their operational autonomy.

**Purposes of the Study**

Because the freight consolidation terminal appears to be a promising alternative to the current freight distribution structure, a comprehensive study is necessary to gain better insight into its feasibility and desirability. This research study is one part of a three-part study.

Part I of the study was conducted by McDermott (1973) and concentrated on pickup and delivery routings and examined the expected social and economic benefits of handling
the small shipment through a consolidation terminal. McDermott's study has supported the economic feasibility of the consolidation terminal.

Part II, conducted by Cadotte (1974), involved the conceptual design of terminal facilities. Cadotte analyzed the long-run investment requirements in terms of size and timing, examined the trade-off of capital investment and efficient operation, and investigated the sensitivity of demand on capacity planning.

Part III is concerned with determining the number and location of consolidation terminals within an urban area in terms of total system cost. The results presented in this dissertation focused on this third phase of the research.

In general, a decision on terminal location is final, and once it is made, the capital expenditure and time frame involved are such that relocation is not feasible in the short run. Because there have been no studies addressed to this subject, the issue of the economic feasibility of the freight consolidation terminal concept has yet to be resolved. Therefore, one of the objectives of this research was to identify the decision variables and their relationship with regard to the number, location, and allocation patterns for the consolidation terminals. A large number of decision variables were involved in
evaluating the number and location of the consolidation terminal(s). These variables were integrated by a model into a functional relationship that determined the trade-off between single versus multiple terminals, CBD vicinity versus suburban locations, and the combinations of number and sizes of the consolidation terminals. Once this decision model was constructed, a solution technique had to be designed which would systematically and efficiently solve the model. Therefore, the second objective of the study was to formulate a mathematical model for the consolidation terminal site selection problem and to design a solution technique for the model.

The solution which was then generated would vary, depending on the conditions and the constraints specified by the planner. Alternating or relaxing certain constraints would enable the planner to clarify the site selection problem. Therefore, the third objective of this study was to measure the sensitivity of the heuristic solutions to the related constraints by comparing the solutions to the site selection problem with the constraints which vary the number, sizing and location of the consolidation terminals.
**Scope of the Study**

The scope of this study included the examination of the number, sizing, and location of the consolidation terminal system for Columbus, Ohio. It was one part of a three-part investigation into the economic feasibility and desirability of freight consolidation for Columbus. The study investigated the economic benefits potentially available from the consolidation of pickup and delivery operations in the Columbus central business district. Although the study focused on the Columbus case, the methodology developed would be applicable to consolidation terminal feasibility studies for any metropolitan area.

In the course of evaluating the economic feasibility of freight consolidation, six candidate terminal sites were investigated. They were all located on or adjacent to a major highway artery, either outerbelt or through highway, with sufficient land area to establish a terminal. These sites were investigated for a one, two, three, or four-terminal system. The terminal was assumed to operate with the conveyor with non-power bump-off spurs recommended by Cadotte (1974).

Two categories of shipment size were investigated in this study; general freight up to 1,000 pounds and shipments less than 5,000 pounds, flowing into and out of the
Columbus CBD via private or public (for-hire) carriers stationed outside the CBD. The latter category was included in order to determine the sensitivity of the shipment size to the economic feasibility of the consolidation terminal. Excluded from the scope of this study were bulk movements, perishable product shipments, and shipments transported by specialists in very small shipment distribution, namely the Postal Service, United Parcel Service and Railway Express Agency.

**Data Base**

The data base for the demand requirements in the CBD, as well as for inbound and outbound transhipment requirements, was constructed from McDermott's cordon crossing study in November, 1972 in Columbus, Ohio. A demand distribution was then developed from this data base, replicating both the private and public terminals' shipments, destinations, and origins within or beyond the CBD.

The projection for future demand requirements in the CBD was estimated from information from the base year, 1972, adjusted with the projected growth rate derived by Cadotte (1974) for the period 1974 - 1985.

Land cost information was obtained from industrial sources; terminal construction, facility set-up, and labor
costs were derived from Cadotte's study; and standard truck operating costs were obtained from trucking industry sources. This cost information was then formulated in a functional relationship for the evaluation of the total system cost.

Model Development and Research Methodology

The consolidation terminal site selection problem is a special case of the location-allocation problem, the characteristics of which were taken into consideration in this study for the formulation of a linear integer programming model. The model developed is a general model of the terminal site selection problem which can be applied to any metropolitan area for this same type of study.

The model calls for classification of the central business district into zones to enhance the study of routing, scheduling, and reliable service for the pickup and delivery of small shipments by the consolidation terminal. Likewise, the truck operators in the metropolitan area were grouped into finite clusters.

The cost relationships were defined, and the derivation of input parameters of the model were specified. An heuristic solution technique for the consolidation terminal site selection model was designed in order to deal with the
integer solution requirement and with the nonlinear nature of the terminal operating cost. The heuristic procedure utilized a linear programming algorithm and was found to be efficient. For example, in the Columbus case study, it took only two iterations to converge in every specified experiment condition.

Model Experimentation

The objective of this research was to determine the number, sizing, and location of the consolidation terminal sites. The framework for achieving the study's objectives was a terminal site selection model, which minimized the total consolidation terminal system cost, subject to the constraint that each CBD zone be served by one terminal only, and that each truck cluster also be served by one consolidation terminal only. By assigning zones and clusters to a particular consolidation terminal, the planner, in effect, determines the volume to be processed through the terminal and, consequently, the capacity of the terminal. Therefore, lower and upper limits of the terminal's capacity were subject to constraints. Also, the number of consolidation terminals designated for each computer run was also specified in one of the constraints.

The terminal site selection model was formulated as
a linear integer model. The solution technique developed for the model utilized a linear programming computer algorithm for the initial solution, followed by an iterative heuristic solution approach in order to: (1) entertain only integer values of the binary variables and (2) adjust for the nonlinear objective function for an heuristic solution.

With the heuristic terminal site selection solution as the tool for analysis, the sensitivity of various numbers of consolidation terminals and the economic feasibility of freight consolidation were investigated through a series of experiments. The format of the investigation called for the construction of the terminal site selection model under various contrasting experimental conditions, and then to have the heuristic programming seek the heuristic solution under each condition. By formulating the terminal site selection computer runs such that the only difference between them was the number of the terminals, the total system costs could be compared. If the difference between the heuristic solution exceeded a specified significance level, then the null hypotheses for the relative equivalence of the contrasting conditions was rejected.
Conclusions Relative to the Research Hypotheses

In order to ascertain the economic feasibility of freight consolidation and the optimum number, sizing and location of the terminals for the Columbus, Ohio, central business district, four experiments, testing five hypotheses, were conducted. The results of these tests and their concomitant conclusions are dealt with in the following discussion, which encompasses these four topical areas: single versus multiple terminal, CBD vicinity versus outer-belt terminal(s), 1,000-pound versus 5,000-pound upper-bound shipment size, and the effects of clustering freight operators' terminals around the new consolidation terminal(s).

Single Versus Multiple Terminal

In this first experiment, hypothesis 1 specifically examined the number of terminals which would result in a minimum system cost when all the terminals are located in the outerbelt area. The number of possible terminals ranged in this experiment from one to four. The results of the experiment were examined at two cost levels. One level was at the operating and shipment cost derived from this study (see Table 4-1, Column 5), which showed a significant 28.7 percent difference between the single terminal and the two-terminal systems. However, on the total system
cost level (see Table 4-1, Column 7), the difference was slightly over the threshold five percent level. Due to this marginal economic difference, the service level under the single terminal and two-terminal systems was examined. The two-terminal system, or any multiple terminal system, would require some transhipment among the consolidation terminals and would thus result in double sorting and longer service time. Therefore, for a better service level, a single terminal would be preferred. Furthermore, in the two-terminal case, the solution demonstrated the dominance of one terminal, site 6, which would serve most of the CBD zones and truck clusters, while the second terminal, site 2, would serve only one CBD zone and two truck clusters. With the requirements of heavy initial setup investment and large overhead of terminal operation, the single terminal could take advantage of its economy of scale. Three and four-terminal cases compounded the two-terminal difficulties. Each additional terminal would serve only one CBD zone and one truck cluster, and, therefore, would not provide any saving on transportation costs owing to increased transhipment among the consolidation terminals and consequent increased operating costs.

One important by-product of the experiment was the observation that when the two-terminal case resulted in a higher system cost than the single terminal case, any
additional number added to the system would result in a still higher system cost (see Table 4-1). Therefore, whenever any one of the additional number of consolidation terminals results in a higher system cost, no further search may be necessary.

CBD Vicinity Versus Outerbelt Terminals

Experiment 2 was designed to examine the effect of location on the system cost of the freight consolidation terminal for the Columbus CBD. The considerable land requirement of such a terminal rendered a candidate site within the CBD impossible. However, a candidate site near the CBD, the old Penn-Central railroad yard, was selected for investigation. Since both CBD vicinity site 5 and outbelt site 6 were within five percent of the threshold cost figure, they had to be considered on other merits, such as future growth potential.

The system cost consists of two components. The first component consists, on the one hand, of the operating cost, including rent, building, equipment, personnel overhead costs, and on the other hand of transportation costs, both between truck clusters and the consolidation terminal and between the consolidation terminal and the CBD zones. The second component is the pickup and delivery costs within the CBD zones, which is responsible for about
eighty percent of the total system cost. The first component of operating and transportation costs is relatively small in comparison with this second component. Thus, the differential economic cost derived from various locations will vary within a few percent only on the total system cost scale. For example, site 5 is only 1.5 percent lower than site 6. Therefore, in the final determination of the terminal site, other pertinent factors should be considered before the conclusion is drawn. For site 5 and site 6, further analysis will be presented in this chapter.

Consolidation of Shipment Sizes of 1,000 Pounds Versus 5,000 Pounds

In the process of investigating the economic feasibility and desirability of small shipment consolidation for the CBD, the sensitivity of the shipment size was also examined. Experiment 3 focused on the economic savings associated with small shipments up to 5,000 pounds, and compared these to the up-to-1,000-pounds shipment investigated earlier. The experiment confirmed McDermott's observation that ninety percent of consolidated small shipment savings are generated from the up-to-1,000-pound category. Shipments between 1,001 and 5,000 pounds were estimated to comprise ten percent of the total number of shipments up to 5,000 pounds, while their weight was
slightly over fifty percent of the total weight.

The sharp increase in costs of shipments between 1,000 and 5,000 pounds, excepting transportation costs, was due to two major factors: increased queuing time at the terminal dock for loading and unloading, and increased loading and unloading time in the CBD. Thus, from the standpoint of economic feasibility, it appears that the consolidation terminal should concentrate on small shipments up to 1,000 pounds.

Trends of Private and For-Hire Truck Operators

Experiment 4 focused on the effects of a possible trend of private and for-hire freight operators to reallocate their terminals in the vicinity of the consolidation terminal. The main advantage of such reallocation is the eventual reduction of transportation costs to a minimum. Hypothesis 5 was developed to determine the economic consequences, should such a trend materialize.

In this study, the concept of terminal reallocation played an important role in determining the location of the consolidation terminal. For example, experiment 2 demonstrated that, from a purely economic point of view, site 5 was a better choice than site 6, although not by a convincing magnitude. The variance was still within the five percent threshold figure. However, further analysis
revealed that more land was available for terminal reallocation around site 6 than around site 5. Thus, in view of the possible future trends of freight operators, site 6 could become the more attractive choice.

The results of all four experiments strongly suggest that a single terminal be located at either site 5 or site 6. If a better potential for future allocation of private and for-hire truck operators' terminals is desired, then site 6 is preferable, despite its slightly higher system cost. Either site should perform freight consolidation of general commodity up to 1,000 pounds, which will entail an economic savings of $1,518,331 annually (Table 5-1).

In addition to the economic benefits provided by a consolidation terminal, there are a number of environmental benefits: reduction of traffic congestion, overall energy consumption, and air and noise pollution in the CBD. The consolidation terminal's potential for yielding highly positive results marks it as a superior alternative to the present system.
TABLE 5-1

COMPARISONS OF THE SINGLE CONSOLIDATION TERMINAL SYSTEM VERSUS THE CURRENT SMALL SHIPMENT SYSTEM IN THE COLUMBUS CENTRAL BUSINESS DISTRICT
(Shipment Size ≤ 1000 Pounds)

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Operating &amp; Shipment</th>
<th>Pickup and Delivery Within CBD&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Total</th>
<th>Current System Cost&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 5</td>
<td>$232,094</td>
<td>$1,165,500</td>
<td>$1,397,594</td>
<td>$2,937,500</td>
</tr>
<tr>
<td>Site 6</td>
<td>$253,669</td>
<td>$1,165,500</td>
<td>$1,419,169</td>
<td>$2,937,500</td>
</tr>
</tbody>
</table>

<sup>a</sup>,<sup>b</sup>These figures are derived from McDermott's study (1973).
Contributions of the Research

Management of Small Shipment

This research study, as stated earlier, is one part of a three-part study which evaluates the economic feasibility of implementing the urban consolidation terminal system for small shipments in the CBD. The evidence presented in this study strongly suggests that small shipment consolidation will yield positive economic benefits.

The study also demonstrates the relationship between the number and location of the consolidation terminals and the performance of freight consolidation in terms of local distribution efficiency and economic benefits. The findings should facilitate the implementation of the consolidation terminal system, and should thus aid in the improvement of small shipment management.

City Planning for Freight Movement

Although efforts have been made to develop comprehensive transportation plans for the movement of people in urban areas, the integration of freight movement into these plans has been largely neglected. This lack of integral planning may be attributed to the distribution structure of shipments in urban areas. The consolidation terminal concept seeks to simplify this distribution structure and so relieve the CBD of a major source of traffic congestion and
air and noise pollution.

City planning will additionally be affected by the possible reorganization of the geographic pattern of truck operators' terminals. Since the study demonstrates that a relationship exists between the consolidation terminal and the truck operators' terminals in terms of local distribution efficiency, truck operators may relocate their terminals to best utilize the consolidation terminal in extending this efficiency. Such relocation would have long-range implications for the movement of freight and people and for land-use planning. Therefore, city planning for freight movement should interact with the consolidation terminal site selection process in order to make an integral and balanced freight movement plan for the city.

**Location Theory**

The consolidation terminal site selection problem was formulated as a linear integer programming model which recognized such characteristics of the problem as: the existence of as many sources as destinations, highly concentrated distribution activities within the central business district, and the clustering of freight operators throughout the metropolitan area. The model took into consideration the nonlinearity of the operating cost function and revised it as a 0-1 integer programming model in
order to utilize the existing computer algorithm for the solution techniques.

Two solution techniques were developed to solve the model. One used Woiler's algorithm for the single terminal case. The other, for the multiple terminal case, was an heuristic solution technique utilizing the linear programming algorithm to derive an heuristic solution which contended with both the integer solution and the nonlinear operating cost function. The heuristic solution was designed to solve the terminal site selection model efficiently and was found to converge in a few iterations.

The formulation of the problem and the heuristic solution technique, which contended with both the integer value and the nonlinearity, will aid the public or private terminal site selection problem in particular, and locational analysis in general.

The research study may be adopted to determine the allocation of consolidation terminal sites for any metropolitan area according to the flow chart shown as Figure 5 - 1, and the detailed steps outlined in Appendix E.
Figure 5.1. Flow Chart for Research Steps for Consolidation Terminal Site Selection.
Suggestions for Further Research

A logical extension of this research would be the amplification of the research model developed in the study. The amplification could take several directions:

1. Consider the impact of assigning more than one consolidation terminal to serve each CBD zone and truck cluster under the multiple consolidation terminal system. This study would determine the trade-off between the increased cost of serving CBD zones and truck clusters through the multiple terminal and the elimination of the transshipment cost.

2. Consider the multiple objectives of the model. The model in this study evaluates only the economic factors of consolidation terminal allocation and treats the social factors (e.g., traffic congestion, air and noise pollution, energy consumption) as dependent variables. The latter are evaluated when the economic cost differential is insignificant. An effective, objective and systematic way of incorporating the social factors into the economic factors objective function would certainly enrich the model.
3. Develop an efficient solution technique, such as the partial (implicity) enumeration method, which would effectively deal with the binary solution values and the setup cost of the consolidation terminal.

A second approach could be a comprehensive study on the implications of the consolidation terminal concept on the private and for-hire freight operators, from the standpoints of economic consequences and operational arrangements. Since the study is "macro" in nature, the economic and social benefits are measured from the current distribution structure and applied to the consolidation terminal concept. An essential element for the successful implementation of the consolidation terminal for small shipments in the central business district would be the cooperation and support of the freight operators. Therefore, a study is recommended that would measure the economic gain a freight carrier may expect to experience and would determine the operational arrangements that would insure the carrier's control over the shipments.

A third area of further research could be an extension of the operational arrangement study. Such a study would investigate alternative ways of handling shipments between the consolidation terminal and the freight carriers, especially in multiple terminal situations. In order to
avoid unnecessary transhipment among the consolidation terminals, some means of assigning shipments to individual carriers is necessary. The assignment procedures should be evaluated from both the economic and legal aspects in order to maintain fairness to all carriers and efficiency within the consolidation terminal system. The study would be particularly important to cities such as New York and Los Angeles with large central business districts and wide-spread metropolitan areas where a multiple consolidation terminal may be required.

The study conducted here focused on the economic feasibility of small shipment consolidation and the allocation of terminal sites. A further investigation into the impact of the consolidation terminal on the "regional development" of its vicinity and the impact on the overall freight, small shipments, and other movement within and without the central business district might provide additional insight into terminal site selection.

Finally, the success of a research study depends not only on the research model, but also on the data base from which the data is generated for the model to evaluate and to analyze. The relationship between the data base and the model construction is shown in Figure 5 - 2. Further research on developing methods and approaches for effective
Figure 5 - 2. Flow Chart of Relationship Between Model Construction and Data Base.

construction of data bases for consolidation terminalfeasibility studies is recommended.

**Summary**

This chapter presented a comprehensive discussion of the research study. The statement of the problem, the study's purposes, its scope, and its data base were summarized, as was the research methodology and model experimentation. The conclusions resulting from the research hypotheses were then discussed, and specific contributions of the study were presented, as they related to small shipment management, city planning for freight movement, and the location theory. The chapter concluded with suggestions for further research.
APPENDIX A
APPENDIX A

GLOSSARY OF TERMS

Included below are those terms which appeared in the text, and which were either not explicitly defined or were defined only once.

Central Business District (CBD):

An urban region, generally located in a downtown area, which has the greatest concentration of commercial and light industrial facilities in terms of retail and wholesale operations, office space, service shops and light manufacturing and non-manufacturing industrial concerns.

CBD Zone:

A small, defined area within the CBD, arbitrarily created to enhance the study of routing, scheduling, and reliable service for the pickup and delivery of small shipments by the consolidation terminal.

Current System Cost:

Total cost of pickup and delivery in the CBD incurred by all small shipment carriers, private and for-hire, as estimated by McDermott's study (1973).
Operating Cost:

The combined fixed and variable costs associated with consolidation terminal operation, including land cost, building cost, material handling system cost, and manpower cost.

Pickup and Delivery Cost Within the CBD:

The cost associated with the consolidation terminal's scheduling and making the pickups and deliveries within the CBD, as estimated by McDermott (1973).

System Cost of the Consolidation Terminal System:

Total cost incurred under the consolidation terminal system in the handling of small shipments destined to or originated from the CBD; includes (terminal) operating costs, CBD pickup and delivery costs, and transportation costs both to and from the CBD zones, and also between the truck clusters and the consolidation terminal.

Transhipment:

Shipment from one consolidation terminal to another, occurring when a truck cluster served by one consolidation terminal receives a shipment destined to a CBD zone served by another consolidation terminal.
Transhipment Cost:
Cost incurred when transhipment is made.

Truck Operator Cluster:
Group of truck operators, arbitrarily defined by geographical location.
A forecast of the daily pickup and delivery requirement relative to central business district zones and truck operator clusters was developed in five major steps. First a classification of CBD zones and truck operator clusters was made, based on McDermott's 1972 cordon crossing study. Second, the probability distributions of the freight pickup and delivery requirement for the CBD zones and the operator clusters was constructed from the same cordon crossing study. Third, estimates of the average daily freight pickup and delivery were derived from the same cordon crossing study with seasonal adjustment for the base year, 1972. Fourth, the annual growth rate from 1974 to 1985 was obtained from Cadotte's study (1974). Finally, the average daily forecast was constructed from the base year figure, adjusted with the growth rate for each given year during the 1974-1985 planning horizon, and then the daily requirement of each of the CBD zones and truck clusters was forecasted, based on the probability distributions.
Classification of CBD Zones and Truck Operator Clusters

McDermott's study classified Columbus CBD zones according to floor-space inventory measures of each zone relative to the total of the CBD. McDermott observed that a balance of such floor space among the zones would keep the service level to each zone approximately the same. Experiments were then conducted to determine whether the CBD should be broken down into four, ten, or twelve zones, keeping in mind that since the freight destined to or originated from the CBD zones will fluctuate daily, each zone's size configuration should be large enough to hold relatively steady the total weight of the freight within the zone. In the ten-zone breakdown, the number of trucks dispatched to each zone ranged from five to nine. In the twelve-zone breakdown, the range was from two to twelve trucks, thus making it less preferable than the ten-zone breakdown. The four-zone breakdown was also found to be more costly than the ten-zone (McDermott, 1973, pp. 107-112), so the ten-zone was adopted for this study. (See Figure B-1).

The determination of truck operator clusters required a different approach. Although a few major concentrations of truck operators exist, the truck operators on a whole are spread out over the entire metropolitan area. Therefore, the clustering was done according to their relative physical locations and each cluster was large enough to hold
Figure B - 1. Map of the Columbus, Ohio CBD: Ten Zones
relatively steady the total weight of the freight within the cluster. In highly concentrated areas of truck operators, each cluster involved a small land area. In locations where truck operators are scattered, the cluster covered a larger land area. (See Figure B-2).

Probability Distribution of the Freight Pickup and Delivery Requirement for the CBD Zones and the Truck Clusters

Since freight characteristics, such as number and weight of shipments, are largely dependent on the type of land use in the CBD, the probability distribution was constructed according to respective land uses: retail goods, retail service, office buildings, and industry. Table B-1 shows the probability distribution of the number of shipments according to zone and land use. Table B-2 shows the probability distribution of weight class of shipments according to land use. Table B-3 shows the probability distribution of weight classes of shipments pickup in the CBD according to land use. These distributions were derived from McDermott's 1972 cordon crossing.

The probability distribution for the truck operator clusters is shown in Table B-4. Since the number of samples was insufficient for determining the probability distribution of the operators' pickup service, it was assumed to be the same as for the delivery service.
Figure B-2. Map of Twelve Truck Operator Clusters.
TABLE B-1

PROBABILITY DISTRIBUTION OF THE NUMBER OF SHIPMENTS
ACCORDING TO ZONE AND LAND USE\textsuperscript{a}

<table>
<thead>
<tr>
<th>Zone</th>
<th>Retail Goods</th>
<th>Retail Service</th>
<th>Office</th>
<th>Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.078</td>
<td>.100</td>
<td>.158</td>
<td>.089</td>
</tr>
<tr>
<td>2</td>
<td>.050</td>
<td>.098</td>
<td>.111</td>
<td>.181</td>
</tr>
<tr>
<td>3</td>
<td>.117</td>
<td>.200</td>
<td>.009</td>
<td>.181</td>
</tr>
<tr>
<td>4</td>
<td>.036</td>
<td>.257</td>
<td>.217</td>
<td>.060</td>
</tr>
<tr>
<td>5</td>
<td>.085</td>
<td>.037</td>
<td>.097</td>
<td>.098</td>
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<td>6</td>
<td>.270</td>
<td>.239</td>
<td>.145</td>
<td>.025</td>
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<tr>
<td>7</td>
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</tr>
<tr>
<td>8</td>
<td>.072</td>
<td>.080</td>
<td>.115</td>
<td>.094</td>
</tr>
<tr>
<td>9</td>
<td>.093</td>
<td>.045</td>
<td>.086</td>
<td>.075</td>
</tr>
<tr>
<td>10</td>
<td>.095</td>
<td>.103</td>
<td>.021</td>
<td>.129</td>
</tr>
<tr>
<td>Total</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Source: McDermott, 1973, p. 189
### TABLE B-2

**PROBABILITY DISTRIBUTION OF THE SHIPMENTS DELIVERY TO CBD ACCORDING TO WEIGHT CLASS AND LAND USE**

<table>
<thead>
<tr>
<th>Weight Class</th>
<th>Retail Goods</th>
<th>Retail Service</th>
<th>Office</th>
<th>Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 100 lbs.</td>
<td>.265</td>
<td>.585</td>
<td>.513</td>
<td>.235</td>
</tr>
<tr>
<td>101-200</td>
<td>.218</td>
<td>.140</td>
<td>.231</td>
<td>.235</td>
</tr>
<tr>
<td>201-500</td>
<td>.265</td>
<td>.140</td>
<td>.102</td>
<td>.256</td>
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<tr>
<td>501-1000</td>
<td>.166</td>
<td>.083</td>
<td>.057</td>
<td>.146</td>
</tr>
<tr>
<td>1001-5000</td>
<td>.034</td>
<td>.052</td>
<td>.097</td>
<td>.128</td>
</tr>
<tr>
<td>Total</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

TABLE B-3

PROBABILITY DISTRIBUTION OF THE SHIPMENTS PICKUP TO CBD ACCORDING TO WEIGHT CLASS AND LAND USE<sup>a</sup>

<table>
<thead>
<tr>
<th>Weight Class</th>
<th>Retail Goods</th>
<th>Office</th>
<th>Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 100 lbs.</td>
<td>0.367</td>
<td>0.286</td>
<td>0.484</td>
</tr>
<tr>
<td>101-200</td>
<td>0.266</td>
<td>0.214</td>
<td>0.161</td>
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<tr>
<td>201-500</td>
<td>0.367</td>
<td>0.143</td>
<td>0.144</td>
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<tr>
<td>501-1000</td>
<td>0</td>
<td>0.158</td>
<td>0.116</td>
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<tr>
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<td>0.095</td>
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<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

TABLE B-4

PROBABILITY DISTRIBUTION OF SHIPMENT HANDLING BY TRUCK OPERATOR CLUSTERS

<table>
<thead>
<tr>
<th>Clusters</th>
<th>Number of Shipments</th>
<th>Weight</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0.085</td>
<td>0.085</td>
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<tr>
<td>2</td>
<td>0.180</td>
<td>0.180</td>
</tr>
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<td>0.195</td>
<td>0.195</td>
</tr>
<tr>
<td>4</td>
<td>0.014</td>
<td>0.014</td>
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<td>5</td>
<td>0.043</td>
<td>0.043</td>
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<tr>
<td>6</td>
<td>0.020</td>
<td>0.020</td>
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<td>0.163</td>
<td>0.163</td>
</tr>
<tr>
<td>8</td>
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<td>0.015</td>
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<td>0.023</td>
<td>0.023</td>
</tr>
<tr>
<td>10</td>
<td>0.052</td>
<td>0.052</td>
</tr>
<tr>
<td>11</td>
<td>0.030</td>
<td>0.030</td>
</tr>
<tr>
<td>12</td>
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</tr>
<tr>
<td>Total</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>
Average Daily Pickup and Delivery for the Base Year, 1972

McDermott's cordon crossing study, conducted on Thursday and Friday, November 16 and 17, 1972, disclosed 2,460 deliveries weighing 1,132,000 pounds, and 570 pickups weighing 227,000 pounds. The average daily pickups and deliveries were determined by first adjusting the survey results according to the weekly index for Thursday and Friday. Shapiro (1974) estimated that the inbound freight represented about 17.86 percent of the week's total inbound freight, and that the outbound freight represented about 20 percent of the week's total outbound freight. The figures were further adjusted according to the November seasonal index, which Cadotte (1974) showed to be .9824. The average daily pickups and deliveries were then computed as follows:

Average Daily Pickups = (Pickups Observed/.1786) x 1/5 x .9824; and

Average Daily Deliveries = Deliveries Observed/.20) x 1/5 x .9824.

Freight Growth Rate

Cadotte (1974) observed that the relationship between GNP and local freight volume during the period 1960 to 1972 could be expressed by a regression coefficient of
1.12884. This coefficient was applied to the estimated GNP growth rate for the 1970's, projected by Faucett Associates, Inc. (1973, pp. 2-4, 2-5), at the lower bound 3.5 percent, the most likely 4.3 percent, and the upper-bound 5 percent. From this association, Cadotte (1974) estimated that the growth rate of local freight would be 3.96 percent, 4.86 percent, and 5.65 percent respectively.

Forecast Average Daily Delivery and Pickup

After obtaining the average daily pickup and delivery for base year and growth rate during the 1974-1985 planning horizon, the projected daily shipment can be derived by adjusting the growth rate to the base year and each year thereafter, as shown in Table B-5.

From the projected daily shipment came the forecast of the number and weight of the deliveries and pickups from the CBD zones (Table B-6 and B-7, respectively) and the number and weight of deliveries and pickups between the CBD zones and the truck operator clusters (Table B-8).
# TABLE B-5

PROJECTED DAILY SHIPMENT VOLUME

1974 - 1985

<table>
<thead>
<tr>
<th>Year</th>
<th>Pessimistic Estimation</th>
<th>Most Likely Estimation</th>
<th>Optimistic Estimation</th>
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</thead>
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<tr>
<td></td>
<td>Pickup Delivery</td>
<td>Delivery</td>
<td>Pickup Delivery</td>
</tr>
<tr>
<td>1974</td>
<td>599</td>
<td>2,584</td>
<td>612</td>
</tr>
<tr>
<td>1975</td>
<td>630</td>
<td>2,688</td>
<td>644</td>
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<tr>
<td>1976</td>
<td>656</td>
<td>2,799</td>
<td>677</td>
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<tr>
<td>1977</td>
<td>683</td>
<td>2,913</td>
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<td>1978</td>
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<td>1979</td>
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<td>804</td>
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<td>1985</td>
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</table>
### TABLE B - 6

**FORCASTED DAILY DELIVERY REQUIREMENT**

<table>
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<tr>
<th>ZONE</th>
<th>RETAIL PIECES</th>
<th>GOODS WEIGHT</th>
<th>RETAIL PIECES</th>
<th>SERVICE WEIGHT</th>
<th>OFFICE PIECES</th>
<th>WEIGHT</th>
<th>INDUSTRIAL PIECES</th>
<th>WEIGHT</th>
<th>TOTAL PIECES</th>
<th>TOTAL WEIGHT</th>
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<td>18009</td>
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<td>8210</td>
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<td><strong>679</strong></td>
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<td><strong>522</strong></td>
<td><strong>193943</strong></td>
<td><strong>651</strong></td>
<td><strong>526307</strong></td>
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<td></td>
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</table>

**TOTAL SHIPMENT** 2607  **TOTAL WEIGHT** 1199214
## TABLE B - 7

**FCRCASTEC DAILY PICK-UP REQUIREMENT**

<table>
<thead>
<tr>
<th>ZONE</th>
<th>RETAIL PIECES</th>
<th>GROSS WEIGHT</th>
<th>RETAIL SERVICE PIECES</th>
<th>WEIGHT</th>
<th>INDUSTRIAL PIECES</th>
<th>WEIGHT</th>
<th>TOTAL PIECES</th>
<th>TOTAL WEIGHT</th>
<th>DELIVERED PIECES</th>
<th>PICKUP WEIGHT</th>
</tr>
</thead>
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<td>141512</td>
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<td>2752</td>
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<td>35818</td>
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<td>39600</td>
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<td>189347</td>
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<td>3</td>
<td>6600</td>
<td>13</td>
<td>5155</td>
<td>25</td>
<td>11935</td>
<td>45</td>
<td>17956</td>
<td>399</td>
<td>148515</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>1948</td>
<td>7</td>
<td>2400</td>
<td>41</td>
<td>14581</td>
<td>59</td>
<td>23077</td>
<td>263</td>
<td>126549</td>
</tr>
<tr>
<td>6</td>
<td>35</td>
<td>6004</td>
<td>10</td>
<td>3439</td>
<td>10</td>
<td>4776</td>
<td>55</td>
<td>14224</td>
<td>513</td>
<td>179127</td>
</tr>
<tr>
<td>7</td>
<td>13</td>
<td>2632</td>
<td>3</td>
<td>1032</td>
<td>28</td>
<td>13372</td>
<td>44</td>
<td>16636</td>
<td>214</td>
<td>56157</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>1545</td>
<td>8</td>
<td>2752</td>
<td>39</td>
<td>18626</td>
<td>56</td>
<td>22923</td>
<td>265</td>
<td>133227</td>
</tr>
<tr>
<td>9</td>
<td>12</td>
<td>2060</td>
<td>6</td>
<td>2064</td>
<td>31</td>
<td>14823</td>
<td>49</td>
<td>18929</td>
<td>244</td>
<td>111208</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>2060</td>
<td>1</td>
<td>344</td>
<td>54</td>
<td>25765</td>
<td>67</td>
<td>28193</td>
<td>304</td>
<td>147257</td>
</tr>
<tr>
<td>TOTAL</td>
<td>128</td>
<td>21974</td>
<td>70</td>
<td>24017</td>
<td>415</td>
<td>194194</td>
<td></td>
<td>244245</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL SHIPMENT** | 613 | **TOTAL WEIGHT** | 244245 |

**GRACE TOTAL SHIPMENT** | 3220 | **WEIGHT** | 1443459 |
<table>
<thead>
<tr>
<th>CLUSTER</th>
<th>DELIVERY SHIPMENT WEIGHT</th>
<th>PICKUP SHIPMENT WEIGHT</th>
<th>TOTAL SHIPMENT WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>222</td>
<td>20761</td>
<td>274</td>
</tr>
<tr>
<td>2</td>
<td>465</td>
<td>43964</td>
<td>579</td>
</tr>
<tr>
<td>3</td>
<td>508</td>
<td>47628</td>
<td>628</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>3419</td>
<td>45</td>
</tr>
<tr>
<td>5</td>
<td>112</td>
<td>10503</td>
<td>138</td>
</tr>
<tr>
<td>6</td>
<td>52</td>
<td>4865</td>
<td>64</td>
</tr>
<tr>
<td>7</td>
<td>425</td>
<td>39812</td>
<td>525</td>
</tr>
<tr>
<td>8</td>
<td>39</td>
<td>3664</td>
<td>48</td>
</tr>
<tr>
<td>9</td>
<td>60</td>
<td>5610</td>
<td>74</td>
</tr>
<tr>
<td>10</td>
<td>156</td>
<td>12701</td>
<td>168</td>
</tr>
<tr>
<td>11</td>
<td>78</td>
<td>7327</td>
<td>96</td>
</tr>
<tr>
<td>12</td>
<td>469</td>
<td>43964</td>
<td>579</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>2606</strong></td>
<td><strong>244246</strong></td>
<td><strong>3218</strong></td>
</tr>
</tbody>
</table>
APPENDIX C
APPENDIX C

DESCRIPTION OF ALTERNATIVE SITES FOR CONSOLIDATION TERMINAL ALLOCATION

Cadotte (1974) estimates that a consolidation terminal with a towveyor system would require a 440-foot length and a 226-foot width in order to handle 4,500 shipments, totaling about 550 tons per day, and would also require 100 doors for loading and unloading. The total constructed area, using Cadotte's estimations, would be about 90,000 square feet, which is slightly over two acres. The truck terminal handbook prepared by Thomas Davies (1966) recommends that a modern terminal with safe and easily accessible entrances and exits and sufficient operating and parking grounds for trucks and trailers would require an open land area three to six times the size of the building. On that scale, a consolidation terminal would occupy a total land area of approximately ten acres.

After the determination of the land requirements for a terminal, the formulation of alternative consolidation terminals is based on three factors: easy access to the CBD or to the truck clusters, industrial development zoning, and land availability. The access factor considers
placement on or adjacent to a major highway artery (either innerbelt, outerbelt, or through highway) in a metropolitan area. Zoning and land availability reduce alternative sites considerably, since a consolidation terminal performs a special function of industrial service and must occupy a large land area, as discussed earlier.

Assistance in formulating the alternative sites for the Columbus study comes from an interview with Mr. Hank Lishied, a partner in the commercial and industrial real estate brokerage and development firm of Lee Wears, Inc., which took place on July 10, 1974. Mr. Lishied recommended seven sites for consideration. Because further investigation indicated that one of these sites was not available for terminal purposes, only six alternative sites were formulated for the study (Figure 3 - 4).

None of the six sites are within the CBD. Although an examination of an alternative site within the CBD was originally planned, the consolidation terminal's large land-area requirement precludes the possibility of such a location. Also, high land values in the CBD make the site economically infeasible. Furthermore, a terminal in the CBD would tend to defeat its prime objective of reducing freight traffic in the CBD if truck operators were allowed to pick up and deliver their shipments to the consolidation terminal within that area. To circumvent this last
difficulty would require considerable effort to coordinate and schedule pickups and deliveries at the truck operators' terminals and would also require a tremendously increased capital investment. Therefore, no alternative sites within the CBD have been selected.

Mr. Lishied also provided cost estimates of the land value for each alternative terminal site (Table C-1). These land costs are incorporated into the computer program to generate the operating cost of the alternative consolidation terminals.
TABLE C - 1

ESTIMATED LAND COSTS OF
SIX ALTERNATIVE SITES AND ITS LOCATIONS<sup>a</sup>

<table>
<thead>
<tr>
<th>Site Number</th>
<th>Location</th>
<th>Cost Per Acre&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Land Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Huntley and Highway 23</td>
<td>$30,000</td>
<td>10 - 15 Acres</td>
</tr>
<tr>
<td>2</td>
<td>Hilliard Cemetery and Interstate 270</td>
<td>$20,000</td>
<td>10 - 15 Acres</td>
</tr>
<tr>
<td>3</td>
<td>Interstate 71 and 270</td>
<td>$18,000</td>
<td>10 - 15 Acres</td>
</tr>
<tr>
<td>4</td>
<td>Interstate 270 and Highway 33</td>
<td>$23,000</td>
<td>10 - 15 Acres</td>
</tr>
<tr>
<td>5</td>
<td>Old Penn Central Yard</td>
<td>$25,000</td>
<td>10 - 15 Acres</td>
</tr>
<tr>
<td>6</td>
<td>Frank and Interstate 71</td>
<td>$25,000</td>
<td>10 - 15 Acres</td>
</tr>
</tbody>
</table>

<sup>a</sup>Source: Hank Lishied, Partner of Lee Kears, Inc. a commercial and industrial real estate brokerage and development firm, Columbus, Ohio.

<sup>b</sup>Land cost includes both purchasing cost and land preparation cost.
APPENDIX D

HEURISTIC SOLUTIONS OF TERMINAL
SITE ALLOCATIONS

This appendix presents computer solutions to all the contrasting sets of experiments.
TABLE D - 1

OPTIMAL SOLUTION FOR SINGLE TERMINAL LOCATED IN THE OUTERBELT AREA

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served</th>
<th>Operating and Transportation</th>
<th>Pickup and Delivery in CBD</th>
<th>Total System</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>1,2,3,4,5,</td>
<td>1,2,3,4,5,</td>
<td>$253,669</td>
<td>$1,165,500(^a)</td>
<td>$1,419,169</td>
</tr>
<tr>
<td></td>
<td>6,7,8,9,</td>
<td>6,7,8,9,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>10,11,12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)This figure is adjusted from McDermott's estimate of $835,000.
### TABLE D - 2

**HEURISTIC SOLUTION FOR TWO-TERMINAL SYSTEM**

**ALL TERMINALS LOCATED IN OUTERBELT AREA**

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served</th>
<th>Cost</th>
<th>Cost</th>
<th>Total System</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>7</td>
<td>1,10</td>
<td>$326,483</td>
<td>$1,165,500</td>
<td>$1,491,983</td>
</tr>
<tr>
<td>6</td>
<td>1,2,3,4,5,6,8,9,10</td>
<td>2,3,4,5,6,8,9,11,12</td>
<td>$326,483</td>
<td>$1,165,500a</td>
<td>$1,491,983</td>
</tr>
</tbody>
</table>

*aThis figure is adjusted from McDermott's (1973) estimate of $835,000.*
### TABLE D-3

HEURISTIC SOLUTION FOR THREE-TERMNAL SYSTEM

ALL TERMINALS LOCATED IN OUTERBELT AREA

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served</th>
<th>Operating and Transportation</th>
<th>Pickup and Delivery in CBD</th>
<th>Total System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>1</td>
<td>$415,563</td>
<td>$1,165,500(^a)</td>
<td>$1,581,063</td>
</tr>
<tr>
<td>6</td>
<td>1, 2, 3, 4, 5, 6, 8, 10</td>
<td>2, 3, 4, 5, 6, 7, 9, 10, 11, 12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)This figure is adjusted from McDermott's estimate of $835,000.
# Table D-4

**Heuristic Solution for Four-Terminal System**

All terminals located in outerbelt area

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served</th>
<th>Cost</th>
<th>Pickup and Delivery in CBD</th>
<th>Total System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>4</td>
<td>$469,905</td>
<td>$1,165,500&lt;sup&gt;a&lt;/sup&gt;</td>
<td>$1,635,405</td>
</tr>
<tr>
<td>6</td>
<td>1,2,3,4,6,8,10</td>
<td>2,3,5,6,7,9,10,11,12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>This figure is adjusted from McDermott's (1973) estimate of $835,000.
**TABLE D - 5**

**OPTIMAL SOLUTION FOR SINGLE TERMINAL LOCATED IN CBD VICINITY**

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1,2,3,4,5,</td>
<td>1,2,3,4,5,</td>
<td>$232,094</td>
</tr>
<tr>
<td></td>
<td>6,7,8,9,</td>
<td>6,7,8,9,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>10,11,12</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>$1,165,500a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$1,397,594</td>
</tr>
</tbody>
</table>

*aThis figure is adjusted from McDermott's estimate of $835,000.*
TABLE D - 6

OPTIMAL SOLUTION FOR SINGLE TERMINAL LOCATED IN OUTERBELT AREA

SHIPMENT SIZE UNDER 9,000 POUNDS

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served</th>
<th>Cost</th>
<th>Versus Under 1,000 Pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Operating &amp; Transportation</td>
<td>Pickup &amp; Delivery</td>
</tr>
<tr>
<td>4</td>
<td>1, 2, 3, 4, 5, 6, 7, 8, 9, 10</td>
<td>1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12</td>
<td>$266,657</td>
<td>$1,638,000$</td>
</tr>
</tbody>
</table>

*This figure is adjusted from McDermott's estimate (1973) of $1,177,750.*
## Table D-7

**Heuristic Solution for Two Terminals Located in Outerbelt Area**

*Shipment Size Under 5,000 Pounds*

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served</th>
<th>Operating &amp; Transportation</th>
<th>Pickup &amp; Delivery</th>
<th>Total System</th>
<th>Incremental Cost</th>
<th>Incremental Cost</th>
<th>Net Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>1,10</td>
<td>$330,884</td>
<td>$1,638,000</td>
<td>$1,968,884</td>
<td>$476,901</td>
<td>$611,000</td>
<td>$134,099</td>
</tr>
<tr>
<td>6</td>
<td>1, 2, 3, 4, 5, 6, 7, 8, 9, 10</td>
<td>2, 3, 4, 5, 6, 7, 8, 9, 11, 12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*This figure is adjusted from McDermott's estimate (1973) of $1,177,750.*
## TABLE D-8

**HEURISTIC SOLUTION FOR THREE TERMINALS LOCATED IN OUTERBELT AREA**

**SHIPLMENT SIZE UNDER 5,000 POUNDS**

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served</th>
<th>Operating &amp; Transportation</th>
<th>Pickup &amp; Delivery</th>
<th>Total System</th>
<th>Incremental Cost</th>
<th>Incremental Cost</th>
<th>Net Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>8</td>
<td>$429,279</td>
<td>$1,638,000 *</td>
<td>$2,067,279</td>
<td>$486,216</td>
<td>$611,000</td>
<td>$124,784</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1, 2, 3, 4, 5, 6, 8, 10</td>
<td>2, 3, 4, 5, 6, 7, 9, 10, 11, 12</td>
<td>$429,279</td>
<td>$1,638,000 *</td>
<td>$2,067,279</td>
<td>$486,216</td>
<td>$611,000</td>
<td>$124,784</td>
</tr>
</tbody>
</table>

\*This figure is adjusted from McDermott's estimate (1973) of $1,177,750.
#### TABLE D - 9

**HEURISTIC SOLUTION FOR FOUR TERMINALS ALL LOCATED IN OUTERBELT AREA**

**SHIPMENT SIZE UNDER 5,000 POUNDS**

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served</th>
<th>Operating &amp; Transportation</th>
<th>Pickup &amp; Delivery</th>
<th>Total System</th>
<th>Incremental Cost</th>
<th>Incremental Cost</th>
<th>Net Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>8</td>
<td>3,638,000</td>
<td>$488,724</td>
<td>$2,126,724</td>
<td>$491,319</td>
<td>$1,438,000</td>
<td>$481,724</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>1</td>
<td>3,638,000</td>
<td>$488,724</td>
<td>$2,126,724</td>
<td>$491,319</td>
<td>$1,438,000</td>
<td>$481,724</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3,638,000</td>
<td>$488,724</td>
<td>$2,126,724</td>
<td>$491,319</td>
<td>$1,438,000</td>
<td>$481,724</td>
</tr>
<tr>
<td>6</td>
<td>1, 2, 3, 4, 6, 8, 10</td>
<td>2, 3, 5, 6, 7, 9, 10, 11, 12</td>
<td>$1,177,750</td>
<td>$488,724</td>
<td>$2,126,724</td>
<td>$491,319</td>
<td>$1,438,000</td>
<td>$119,681</td>
</tr>
</tbody>
</table>

*This figure is adjusted from McDermott's estimate (1973) of $1,177,750.*
### Table D-10

**Optimal Solution for Single Terminal Located in CBD Vicinity**

*Shipment Size Under 5,000 Pounds*

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served</th>
<th>Cost</th>
<th>Versus Under 1,000 Pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Operating &amp; Transportation</td>
<td>Pickup &amp; Delivery</td>
</tr>
<tr>
<td>5</td>
<td>1, 2, 3, 4,</td>
<td>1, 2, 3, 4,</td>
<td>$243,697</td>
<td>$1,638,000$^a</td>
</tr>
<tr>
<td></td>
<td>5, 6, 7, 8,</td>
<td>5, 6, 7, 8,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9, 10</td>
<td>9, 10, 11, 12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*This figure is adjusted from McDermott's estimate (1973) of $1,177,750.*
TABLE D - 11

OPTIMAL SOLUTION FOR SINGLE TERMINAL LOCATED IN THE OUTERBELT AREA

TRANSPORTATION COSTS BETWEEN CLUSTERS AND

TERMINAL ASSUMED TO BE MINIMUM

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Operating and Transportation</td>
</tr>
<tr>
<td>6</td>
<td>1,2,3,4,5, 6,7,8,9, 10</td>
<td>1,2,3,4,5, 6,7,8,9, 10,11,12</td>
<td>$135,025</td>
</tr>
</tbody>
</table>

\textsuperscript{a}This figure is adjusted from McDermott's estimate of $835,000.
TABLE D - 12

HEURISTIC SOLUTION FOR TWO Terminals LOCATED IN THE OUTERBELT AREA
TRANSPORTATION COSTS BETWEEN TRUCK CLUSTERS AND CONSOLIDATION Terminals
ASSUMED TO BE MINIMUM

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served a</th>
<th>Cost</th>
<th>Total System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7</td>
<td>1,2,3,4,5,6,7,8,9,10</td>
<td>$220,440</td>
<td>$1,385,940</td>
</tr>
<tr>
<td>2</td>
<td>1,2,3,4,5,6,7,8,9,10</td>
<td></td>
<td>$1,165,500b</td>
<td>$1,385,940</td>
</tr>
<tr>
<td>6</td>
<td>1,2,3,4,5,6,8,9,10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a The truck operators are assumed to be clustered around the consolidation terminals. Their specific locations are not determined.

b This figure is adjusted from McDermott's estimate (1973) of $835,000.
### TABLE D - 14

**Heuristic Solution for Four Terminals Located in the Outerbelt Area**

Transportation costs between truck clusters and consolidation terminals assumed to be minimum.

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served</th>
<th>Cost</th>
<th>Total System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>1, 2, 3, 4</td>
<td>$363,022</td>
<td>$1,528,522</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>4, 5, 6, 7, 8, 9</td>
<td>$1,165,500b</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>10, 11, 12</td>
<td>$363,022</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1, 2, 3, 4, 6, 8, 10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The truck operators are assumed to be clustered around the consolidation terminals. Their specific locations are not determined.*

*This figure is adjusted from McDermott's estimate (1973) of $835,000.*
TABLE D-13

HEURISTIC SOLUTION FOR THREE TERMINALS LOCATED IN THE OUTERBELT AREA
TRANSPORTATION COSTS BETWEEN TRUCK CLUSTERS AND CONSOLIDATION TERMINALS
ASSUMED TO BE MINIMUM

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served a</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Operating and Transport</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>1,2,3,4,5,6,8,10</td>
<td>$305,662</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>1,2,3,4,5,6,7,8,9,10,11,12</td>
<td>$305,662</td>
</tr>
</tbody>
</table>

The truck operators are assumed to be clustered around the consolidation terminals. Their specific locations are not determined.

bThis figure is adjusted from McDermott's estimate (1973) of $835,000.
TABLE D - 14

HEURISTIC SOLUTION FOR FOUR TERMINALS LOCATED IN THE OUTERBELT AREA

TRANSPORTATION COSTS BETWEEN TRUCK CLUSTERS AND CONSOLIDATION TERMINALS

ASSUMED TO BE MINIMUM

<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served</th>
<th>Cost</th>
<th>Total System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td></td>
<td>$363,022</td>
<td>$1,528,522</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>1,2,3,4,6,8,9,10</td>
<td>$1,165,500b</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>1,2,3,4,6,8,9,10</td>
<td>$1,528,522</td>
<td></td>
</tr>
</tbody>
</table>

aThe truck operators are assumed to be clustered around the consolidation terminals. Their specific locations are not determined.

bThis figure is adjusted from McDermott's estimate (1973) of $835,000.
<table>
<thead>
<tr>
<th>Terminal Site</th>
<th>Zone Served</th>
<th>Cluster Served</th>
<th>Operating and Transportation</th>
<th>Pickup and Delivery in CBD</th>
<th>Total System</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1,2,3,4,5, 6,7,8,9, 10</td>
<td>1,2,3,4,5, 6,7,8,9, 10,11,12</td>
<td>$99,542</td>
<td>$1,165,500&lt;sup&gt;a&lt;/sup&gt;</td>
<td>$1,265,042</td>
</tr>
</tbody>
</table>

<sup>a</sup>This figure is adjusted from McDermott's estimate (1973) of $835,000.
APPENDIX E
The research methodology developed in this study can be applied to any metropolitan area, where the required parameters (data) have been properly analyzed, determined, and adjusted. In this appendix, detailed step-by-step directions for applying this research methodology are presented. The presentation will follow the steps of the flow chart shown in Figure E - 1.

**Step 1:**
Determine the base period for the study; that is, the period for which basic data is to be collected.

**Step 2:**
Design a survey technique. The information needed in the survey is as follows: number and weight of shipments destined to and originated from the CBD, and their specific location within the CBD, the truck operators who perform the pick up and delivery and the amount of freight the carriers are responsible for within the CBD, and the cost needed to
Figure E - 1. Flow Chart of Research Steps for Consolidation Terminal Site Selection.
perform these services. McDermott's cordon
crossing survey (1973) provides a good re­
ference for the design of such a survey.

Step 3:
Analyze and tabulate the survey results. Again,
McDermott's study provides a good reference.
The analysis here provides all the basic infor­
mation for the study.

Step 4:
Determine the number of zones within the CBD
which appear to provide more efficient routing,
a reliable and consistent service rate, and
lower costs for the consolidation terminal
operation. The classification of the zones and
determination of the probability distribution is
referred to in Appendix B of this research study.

Step 5:
Determine the number of truck operator clusters
within the metropolitan area being studied. To
make the determination, take the information
obtained in Step 3, and cluster the truck
operators so that every cluster contains about
the same number of truck operators, or about
the same amount of freight. The clustering is
conducted according to the geographical location of each carrier.

**Step 6:**
Construct the alternative terminal sites. Easy accessibility to the CBD or to truck cluster and land availability are two prime factors in considering candidate sites for terminal selection. Appendix C provides more detailed information on this subject.

**Step 7:**
Derive cost information. There are four major cost functions to be determined in order to conduct the study: terminal operating cost, transportation costs between CBD zones and the consolidation terminal(s) and between the truck clusters and the consolidation terminal(s), the cost of performing pick up and delivery in the CBD, and, finally, the transhipment cost among the consolidation terminals within multiple terminal systems. The determination of each of these four cost functions is as follows:
a. The terminal operating cost function is expressed mathematically as follows:

\[ \overline{OC_i} = dr \times LC_i + dr \times (FTC + FF \times VTC) + dr \times (FMC + FF \times VMC) + (FF \times MANC) + OHC \]

where:

- \( \overline{OC_i} \) = operating cost of the consolidation terminal;
- \( dr \) = discount rate;
- \( LC \) = land acquisition cost;
- \( FTC \) = fixed cost of the terminal building;
- \( VTC \) = variable cost of the terminal building;
- \( FF \) = total volume of freight flow;
- \( FMC \) = fixed cost of material handling system;
- \( VMC \) = variable cost of material handling system;
- \( MANC \) = variable cost of manpower for the consolidation terminal; and
- \( OHC \) = overhead cost.

To derive the fixed and variable costs of the terminal building, fixed and
variable costs of the material handling system, variable cost of manpower, and the overhead cost of operating the terminal, readers are referred to Cadotte's study (1974).

b. The transportation costs between the CBD zone and the consolidation terminal are formulated as follows:

\[ c_{ij} = [ (T \times W/\text{DL}) \times \text{DAY} ] \times \text{MC} \]

where

\( c_{ij} \) = cost of pickup and delivery from designated consolidation terminal \( i \) to CBD zone \( j \);

\( T \) = time required to travel (in minutes) from the designated terminal site to the CBD zone \( j \);

\( W \) = total weight shipped (in pounds) from the designated terminal \( i \) to the CBD zone \( j \), or vice versa;

\( \text{MC} \) = cost per minute of operating a freight truck;

\( \text{LD} \) = average truckload weight in pounds by type of truck; and

\( \text{DAY} \) = total number of working days in a year.
The transportation costs between truck operator clusters and the consolidation terminal are formulated as follows:

\[ d_{if} = [ T \times (W/LD) \times F ] \times MC \]

where

- \( d_{if} \) = shipment cost from truck operator cluster \( f \) to consolidation terminal \( i \);
- \( F \) = fraction of a truckload serving as an adjustment factor.

c. The total pickup and delivery cost in the CBD is the most difficult and complicated to derive, because so many variables are involved. These variables include routing, scheduling, number of stops, size of shipments, queuing time at loading/unloading areas, and others. McDermott utilized a simulation model in deriving the pickup and delivery costs in the CBD. Other statistical methods may be used to estimate the cost.
Transhipment costs are treated as a cost added on to the transportation costs, both between the truck clusters (f) and the consolidation terminal (k), and also between the CBD zone (j) and the consolidation (i), and the problem is expressed as follows:

\[ c_{ij}' = c_{ij} + \frac{1}{2} \left[ TS_{ik} \times VOS \right], \]

\[ d_{kf}' = d_{kf} + \frac{1}{2} \left[ TS_{ik} \times VOS \right] \]

where

\[ TS_{ik} = \text{per unit cost of transhipment between consolidation terminal i and k}; \]

\[ VOS = \text{volume transhipped}. \]

**Step 8:**
Formulate the terminal site selection problem as Equation [34] through Equation [42].

**Step 9:**
Apply the heuristic solution technique presented in Chapter III to solve the formulated terminal site selection problem.
Step 10:
Conduct all the contrasting sets of experiments to ascertain the economic effects of varying the number and location of consolidation terminals.

Step 11:
Summarize the findings of the experiments, based on a predetermined threshold figure.

Step 12:
Present recommendations.


Downtown Area Plan. N. Jack Huddle, Director, Department of Development, City of Columbus.


Regional Center Summary of Additional Developments. Division of Planning, Department of Development, City of Columbus, Columbus, Ohio: September 1, 1973.


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