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CHAPTER I

TRUCK TRANSPORTATION IN THE CHANGING METROPOLIS

The Purpose of this Investigation

One of the principal features in the growth of any metropolitan area is the continuous change in its physical, economic, social and political structures. Change is the one feature which all metropolitan areas have in common even though it may manifest itself in different ways from one metropolitan area to another.

Of the many forces which mold the changing physical pattern of an urban area, transportation ranks among the foremost. This is true for the individual city. It is accentuated even more in the metropolis, which owes its very existence to innovations in transportation during the past decades.

Road and rail have been prime media in the spatial expansion of the metropolis. The speed of rail and road transportation has shrunk the time boundaries of the urban area. In doing so it has extended the spatial boundaries far beyond the limits of the original city.

During recent years planners have given serious attention to the development of comprehensive transportation plans. However, emphasis in this field of planning has hitherto been directed predominantly toward the movement of persons. The integration of trucking routes and more especially of truck freight terminals into the transportation plan has been sadly neglected.

There are several reasons for these apparent deficiencies in coordinated transportation planning. First, the demand and supply functions for the common carrier sector of truck transportation have never been suitably defined. Second, because trucks generally constitute a small portion of total vehicle registrations in urban areas, the problems created by heavy concentrations of trucks in certain areas or on certain routes are seldom given the planning attention which they deserve. In the past such problems have been remedied, though not necessarily cured, by regulatory measures. Third, the truck is still too frequently regarded as a mere tool of commerce and industry, instead of as a force in itself, with a forceful impact upon the spatial distribution of certain sectors of commercial and industrial activity.

Planning authorities are by no means unaware of these deficiencies. It is almost surprising, therefore, that to date so little study and research has gone into the field of truck traffic and terminal location patterns.

The objective of this study is to seek a better understanding of the changing distributional patterns of truck freight terminals and truck freight movement within the framework of the changing metropolis. More specifically, it sets out to identify, evaluate and relate those factors which have been effective in producing the current patterns of truck terminals and truck traffic and to determine their joint effect upon changes in these patterns during the past decades. It also proposes to investigate the possible impact of truck transportation on the distributional patterns of the various economic activities which collectively contribute toward the effective functioning of the metropolis.

Selection of a Basic Study Area

Among the numerous metropolitan areas in the United States, the metropolitan area of Chicago was found to be most appropriate for the study of truck freight terminals and truck trip patterns. By virtue of its favorable geographic position, coupled with the enterprising spirit of its citizens, Chicago has emerged as one of the world's greatest focal points in transportation. Its vigorous growth during the past, furthermore, leaves little doubt of its important future role as a pole of attraction to water, air, rail and highway transportation.

The past decade has seen phenomenal changes in the growth of transportation facilities within the metropolitan area of Chicago.

The opening of the St. Lawrence Seaway in 1959 started an entirely new chapter in Chicago's role as a nodal point for inland water transportation. The recent widening of Navy Pier and the erection of warehouses at a total cost of almost three and one-half million dollars give some evidence of the anticipated rewarding future in water transportation (1).

Even more important is Chicago's function as a focal point for air travel. Already Midway Airport is acclaimed as the "world's busiest airport." Anticipating Chicago's continuing importance as a regional, national and international air terminal and transfer point, the City Council in 1958 authorized the issuance of Airport Revenue Bonds to the value of $120,000,000 for the construction of the new O'Hare International Airport.

Railroads, together with barge traffic, have constituted the major feeders of surface transportation into the metropolis since its early days. Presently, some twenty-one trunk railroads converge onto Chicago. Although the plans for consolidated railroad terminals have not yet been put into effect, some 25 piggyback terminals were established within the metropolis during the past decade. The early acceptance of this relatively new mode of freight transportation is a clear indication of the confidence of the private sector of the transportation industry in Chicago's future as a major focal point of transportation.

No less impressive than the progress made in the other segments of transportation and, in fact, by far surpassing it, has been progress in highway transportation. Seven Interstate Routes now converge upon Chicago linking it to all points in the nation. Within the City of Chicago itself an 83.3 mile system of superhighways is presently under construction at a total estimated cost of over one billion dollars (2). Already, forty-one million dollars have been spent by the city government on off-street parking facilities for automobiles.

In 1955 some 1,341,600 automobiles and 130,000 trucks were registered in the metropolitan area of Chicago. Although trucks accounted for only 8.2 per cent of all vehicles registered, they performed 13.7 per cent of all trips. The number of truck trips totaled 827,590 trips per day (3).

On a national scale, Chicago occupies second place in total truck registrations. Cook County with 116,161 motor truck registrations in 1959 was second only to the County of Los Angeles with 321,306 motor truck registrations (4). However, in 1959 Chicago was first in the number of Class I and II carriers registered. (Class I carriers have an average gross operating revenue of $1,000,000 or more annually. Class II carriers have an average gross operating revenue of $200,000 to $1,000,000 annually.) (5) With 128 Class I and II carriers, Chicago outranks both New York and Los Angeles which, with 109 and 86, rank second and third respectively (6). The high concentration of both trucks and large carriers gives evidence of Chicago's importance as a nodal point for regional and national highway freight transportation.

The amount of truck freight movement within the metropolitan area of Chicago is not only reflected in the total number of trucks registered, the total number of daily truck trips performed or in the total number of carriers based in the area, but also by the number of terminal points serving common carriers within the area. At the present time no fewer than 544 carriers have terminal points within the metropolitan area of Chicago (7). All of these carriers are common carriers of general freight.

This brief sketch of Chicago as a focal point for regional, national and international transportation, illustrating the phenomenal changes which have occured in all modes of transportation within the metropolis during the past decade, will form the backdrop against which changes in the distributional pattern of truck freight terminals and truck freight movements will be investigated.

Previous Studies in this Field

The majority of studies on truck freight movement and terminal location thus far produced were prompted essentially by considerations of regulation or location of an individual terminal. They were conducted with the ultimate objective of producing a set of recommendations or plans.

Few, if any, ever attempted to produce theory on the spatial distribution of truck terminals or succeeded in defining the functional and economic relationships in truck terminal operation in relation to the expanding and changing metropolis. This was in spite of the revealing findings in the Milwaukee Study (8) which observed that, although commercial vehicles accounted for only 11 per cent of the total registrations in Milwaukee, this small group of vehicles was responsible for 24 per cent of all trips made in the metropolitan area during the manual weekday. Since the effect of a truck on the traffic stream is equivalent to at least two private passenger vehicles and, furthermore, since commercial vehicles are denied the use of parkways and certain boulevards in that city, the average street is already carrying 35 to 45 per cent commercial traffic. The report concludes: "Considering the relative operating cost of the two types of vehicles, truck traffic now predominates in many cases in the economies of the urban traffic problem."

Other cities where similar locational studies were conducted for the individual terminal or union terminal are Detroit (9), New York (10), Boston (11), Louisville, Kentucky (12), Atlanta, Georgia (13), Philadelphia (14), and Charlotte, N.C. (15).

Current technical magazines on trucking (16), town planning (17) and architecture (18) contain a fair amount of literature on terminals. However, this literature is generally confined to the location, layout and operation of an individual terminal, rather than to the considerations which determine locational patterns.

A more academic approach to truck freight movement within the city is found in a study by Edgar M. Horwood entitled, "Center City Goods

Movement: An Aspect of Congestion" (19). In this study the actual goods movements to and from central business establishments is presented and related to the efficiency of central transport operations and the economics of goods consolidation.

Alexander Klein, in his article, "Solving the Traffic Problem," (20) reviews some of the basic concepts on the transformation of the "centripetal" town, with its congested central area, to the "centrifugal" town system, based upon notions of organical and biological rather than schematic planning of cities.

Perhaps the most important study on truck freight movement and terminal location ever undertaken was conducted by the Committee on Motor Truck Terminals in Chicago (21). A brief review of the resulting report (1950) is given below. The recommendations contained in this report led to a further study by the Chicago Plan Commission in 1953 which is outlined in a report entitled, "Trucking in the Central Business District" (22). Inspired largely by the 1950 study mentioned above, a doctoral dissertation, "Truck Transportation Patterns in Chicago," was produced by Jerome D. Fellmann at the University of Chicago (23).

Study by the Committee on Motor Truck Terminals, Chicago, 1950

In 1949 Mayor Kennelly appointed the "Citizens Committee on Motor Truck Terminals" and charged it with the responsibility of developing a program relative to the place of the motor truck in Chicago's traffic.

The events which prompted the establishment of this study group were the increasing number of terminals located in areas which were never intended for this purpose.

The indiscriminate location of 245 truck terminal buildings occupied by 492 companies, as well as obsolete, inadequate zoning regulations and the lack of proper planning, had resulted in low transportation efficiency.

Apart from the concern produced by the more than tripling of the number of truck registrations during the period 1920-1949, the Committee was faced with the problem of the increased size of the trucking unit. At that time, no records were available on the number of trailers registered in Chicago. However, the records for the State of Illinois showed a registration of 5,068 trailers in 1920. This had increased to 56,453 in 1949, a more than ten-fold increase.

The Committee further found that by 1949 a major portion of certain consumer goods was already carried by trucks. Thus, 89 per cent of live poultry, 90 per cent of milk, 40 per cent of cheese, 80 per cent of eggs, 70 per cent of butter and 25 per cent of all fruit and vegetables arrived in Chicago by truck. In 1925 less than 5 per cent of these products arrived by truck at the South Water Street market.

As far back as 1949 an important function of the terminal was the interchange of freight between carriers. This freight, which constituted at that time 16.5 per cent of the total number of shipments and 27 per cent of the volume in weight of all freight handled by motor carriers, neither originates in, nor is destined to, the City of Chicago, but rather moves from a point outside of the city to another point beyond the city.

An extensive analysis of carrier pick-up and delivery operations was undertaken as part of the study. The city was divided into 46 sections, into which 128,400 truck stops for pick-up and delivery and interchange of freight were classified. From this survey it was learned that less than 5 per cent of all shipments entered the Loop area, bounded by Harrison Street, Lake Street, the River and Lake Michigan. It furthermore provided a guide toward entirely new concepts of truck terminal operation.

The Committee finally came up with a set of recommendations for the location of truck freight terminals. These recommendations called for the establishment of four terminal districts located as follows:

1. Between California and Kedzie from Milwaukee to the edge of the proposed N.W. Expressway.
2. Between Ogden and the Congress Expressway from Western to California.
3. Between Archer and the River from Ashland to Western.
4. Between State and Halsted from 47th Street to the edge of the proposed South Expressway.

These locations with a minimum area of 25 acres each and approximately 2 miles apart would be interconnected by expressways and would have easy access to the new highway network planned for the metropolitan area.

Each terminal would be self-contained and include all essential facilities such as repairs, parking, housing and services.

The location of these areas adjacent to common expressways would permit interchange of freight through the shuttle system without the use of city streets.

Apart from the recommendations on the location of truck terminals, the Committee also made recommendations related to matters such as the establishment of Truck Parking areas, the establishment of a Truck Route

Program and the projection of a plan for consolidation of freight and night-time truck deliveries in the downtown area.

The terminal plan recommended by the Committee was both novel and bold. It was hailed by many in the field of transportation as a revolutionary step toward the solution of the problem of minimizing over-all transportation cost, by minimizing the cost of truck transportation in the collection and distribution of freight, reducing terminal expenses by providing space for efficient terminal operations, and by keeping over-the-road carriers off the city streets.

As is the case with many imaginative schemes, this scheme, as proposed, has never been fully brought into effect. However, it has set the pattern for the future and has thus provided a starting point for Municipal action. At the present time, thirteen zones designated for the use of truck freight terminals exist in the City of Chicago. Indications are that several more are to follow in the near future (1961).

Study Procedure

This investigation sets out with the formulation of a theory which attempts to explain changes in the pattern of truck terminal distribution and truck trips over a period of time. The theoretical formulation is followed by an analytical investigation of terminal location and trip generation. In the final section, actual terminal and truck trip patterns are determined for two selected years, the validity of both the theoretical and analytical approaches appraised in terms of the empirical findings and the discrepancies explained.

CHAPTER II

A THEORETICAL APPROACH TO TERMINAL LOCATION AND TRUCK TRAFFIC PATTERNS

A Theory on the Location of Truck Terminals

As in all other modes of common or public carrier transportation, the terminal of LTL (less than truck load) truck transportation forms an integral part of the entire operating system. Thus, it is essential to find a suitable location for the terminal at which the joint cost of the various elements composing the over-all operation of freight movement and handling is minimized. At the same time all regulatory constraints must be satisfied.

The basic function of the truck terminal is one of breaking up inbound freight shipments and consolidating outbound freight shipments. On the basis of this consideration first impressions might infer the existence of a relationship between the location of a truck terminal and the location of an industry using "pure localized materials" as postulated by Alfred Weber in his theory of industrial location (1). However, a more detailed analysis will reveal that an analogy between the location of truck terminals and that of industrial establishments is weakened considerably, mainly due to the widely varying operational characteristics of the methods of transportation employed.

Changes in the distributional pattern of truck terminals are characteristic of changes in the structure and function of the metropolis.

More specifically, they are dependent upon changes in the pattern of demand for LTL transportation, not only within the metropolitan area, but on a regional basis as well. They are also dependent on changes in supply, in terms of technological innovations in the vehicle, the growth of the carrier, improvements in the roadway system and increased efficiency of terminal handling. Finally, changes in the distributional pattern of truck terminals are influenced to a considerable degree by municipal and Interstate Commerce Commission regulation.

A theory which will explain the distributional patterns of truck terminals must therefore take into account the chronological sequence in the growth of demand, changes in the operating characteristics of truck transportation and changes in regulation. Three time periods have been identified in formulating this theory: the period of the individual operator, the period of growth and the period of consolidation.

1. The Period of the Individual Operator

The early period of LTL common carrier truck transportation was characterized by the individual operator, whose sole operation consisted in the pick-up and delivery of goods, serving commercial and industrial establishments purely on a local basis.

The uncertainty of the future in truck transportation at that time motivated a trend toward short-run profits, with a minimum of capital outlay both for equipment and terminal facilities. The rental or acquisition of a few trucks and an old warehouse or garage were sufficient to set up an operator in the LTL trucking business. The chief limiting factor was the amount of investment he was prepared to risk.

The function of the "terminal" at that time was essentially one of breaking up and consolidating freight shipments, together with such ancillary functions as providing office space, parking and service facilities for trucks.

The light trucking volumes during this early period of truck transportation caused no particular concern to municipal authorities. It was still unnecessary to regulate trucking traffic or to control the location of terminals.

Under these circumstances, the dominating trend in the location of truck terminals was toward commercial and industrial activity. The major objective was immediate maximization of profits, each operator competing with all others and finding little incentive to share a common terminal. In the absence of municipal restrictions, terminals were frequently located in residential zones, adjoining commercial and industrial areas where land was less expensive. A point was generally selected from which a maximum of service could be rendered to all shippers at a minimum of pick-up and delivery cost.

During the period of the individual operator, therefore, the distributional pattern of truck terminals followed closely that of commercial and industrial establishments, whose major area of activity was concentrated within or adjoining the core area of the city and around rail and waterway transportation terminals.

2. The Period of Growth

The second period was characterized by the growth in demand for LTL truck transportation, brought about by the expansion of commercial and industrial activity both at the original site and at new sites, within and beyond the confines of the metropolitan region. This growth was met and encouraged by technological innovations to the road vehicle.

During this period, traffic concentration in and near the downtown area was increasingly discernible; however, not sufficiently to prompt municipal action. Operators foreseeing remunerative potentialities in truck transportation were, furthermore, no longer content with short-run profits. Future customers and existing ones were of equal concern. Internal expansion of the individual company and mergers between companies took place, creating an increasing variety in sizes of carriers. The small carrier was still content with his original location. For the larger carrier terminal space became more and more restricted. Space at a reasonable price was available only further out.

The impact of technological innovations to the road vehicle was perhaps less prominent in intra-metropolitan transportation than it was in inter-metropolitan transportation. Hitherto the chief media for carrying freight between regions had been the rail and the waterway. This period saw the beginnings of an entirely new method of long distance freight shipment -- highway transportation.

The importance of highway transportation in inter-regional freight movement, when related to terminal location, lay in the peculiarities of its operational characteristics. These in turn were a result of Interstate Commerce Commission regulation, limiting the operation of the individual carrier to specific areas and route systems. This had the effect of adding a new function to the truck terminal -- the interchange of freight between carriers operating on a regional basis.

Increased land requirements and higher operating costs of the larger line-haul vehicle in areas of traffic congestion were conducive to terminal location away from the areas of concentrated commercial activity. By substituting interline freight for local pick-up and delivery freight, as terminals moved out, the early ties with the local shipper started to weaken.

The period of growth therefore saw an outward movement of terminals. Those with purely local and regional freight were still attracted towards the shipper, those with high proportions of inter-regional freight tended toward the outer areas, taking advantage of the benefits of substitution between local and inter-line freight.

3. The Period of Consolidation

The third period is essentially a continuation of the previous one. It is a period of further growth, both in the physical structure of the metropolis and in the demand for LTL transportation. However, two features set it apart from the two earlier periods. The first is the increase in volume of interline shipments; the second, the introduction of municipal regulation on the movement of trucks and upon the location of their terminals.

The signs of agglomeration of terminals which became discernible earlier now become more prominent. This trend toward agglomeration is not confined to the large carriers handling a high proportion of inter-line freight, but also to those with lesser volumes of inter-line freight who still prefer to be located closer to the shipper.

The construction of modern highways, skirting the metropolitan area, will produce a further incentive to interline carriers to move out, particularly where radials are provided to give ready access to concentrations of local shippers.

Strong social pressures might be expected in this period of increased truck transportation activity toward the passage of zoning ordinances prohibiting the establishment of truck terminals within zones reserved for residential use and prohibiting the use of trucks on certain thoroughfares.

Such regulation will have one or two of three effects upon the locational pattern of terminals. First, it may lead to agglomeration of terminals within the city boundary by confining the location of terminals to specific truck terminal zones. Second, it may encourage terminal location beyond the limits of the zoning authority, but still within the "commercial zone" as defined by the Interstate Commerce Commission. Third, it may result in a truck terminal area being created first by acquisition of a sufficient tract of land and proclaimed as a truck terminal area or incorporated subsequently into the "commercial zone."

Thus, the period of consolidation is marked by the agglomeration of terminals either near major skirting routes or as close as possible to the shippers. The original force of attraction of commercial and industrial activity has been weakened by changes in the production function of the terminal, by greater land requirements due to larger volumes of freight, by traffic congestion and by municipal regulation.

A theory on the distributional pattern of truck terminals is incomplete without taking into account its impact upon the pattern of physical changes in the metropolitan area. For this purpose it will suffice to look at the final pattern during which relatively permanent agglomerations of terminals emerge, in contrast to the more temporary and scattered pattern of terminals found during the two previous periods. The truck terminal areas of the final period are in some ways comparable to the terminals of other common carriers of general freight.

Throughout the history of transportation, the terminal has always been a strong pole of attraction to that segment of commerce and industry which is oriented toward transportation. Industrial and commercial development in the environment of rail, waterway and, in certain cases, even air terminals sufficiently bears out this contention. It is entirely conceivable that the future truck terminal area might influence the location of commercial and industrial establishments in a similar way. The more versatile operation of the truck and the contribution of other locational forces, such as less costly land and the proximity to major traffic arterials, however, will make it difficult to separate its specific impact.

A Theory on the Changes of the Truck Traffic Pattern

One of the major factors prompting the outward movement of truck terminals was seen to be congestion, both within the terminal and on the street system. Truck terminals are generators of two types of traffic -- traffic due to line-haul vehicles, which may be confined by regulation to specific routes within the city limits, and traffic due to the smaller pick-up and delivery vehicles operated both by the carriers themselves and by cartage contractors.

Considering at the outset only those trucks operating from a terminal, and retaining the three periods of growth used in the theoretical approach to the distributional pattern of truck terminals, the resulting patterns of this sector of the trucking industry may be postulated as follows: During the "period of the individual operator" in which the pattern of truck terminals was determined almost exclusively by the locational pattern of commercial and industrial establishments, the volumes of freight handled were essentially small. The truck itself was small, and the resulting truck traffic concentration was relatively inconsequential.

The "period of growth" resulted in the outward movement of truck terminals. It saw larger and increased numbers of trucks. The pattern of pick-up and delivery trips changed with the changing pattern in demand, which in turn followed the changing patterns of intensity in production and commercial activity. Thus, the first signs of an outward movement of truck trip ends appeared, headed by those of the large vehicle.

This outward movement of the common carrier sector of trucking traffic continued into the "period of consolidation." It was given further impetus by regulations prohibiting the entry of heavy vehicles to the central area and to certain parkways and boulevards, by requiring the line-haul vehicle of the interstate carrier to use only certain routes leading to the terminal, by requiring the line-haul vehicle to change drivers at the terminal in the event of further trips of the vehicle within the city, and by the increased cost of operating large vehicles on streets of growing traffic concentration.

From the foregoing considerations it becomes apparent that the outward movement of truck terminals will lead, in the first instance, to an outward movement of heavy line-haul common carrier vehicles. This does not hold true to the same degree for pick-up and delivery vehicles. Each trip made by the latter type of vehicle to or from the terminal may require a great number of stops within its specific area of operation, depending upon the number of shippers served and the size of shipments handled.

The pattern of truck trip ends and truck traffic flow is not entirely reflected in the pattern set by the LTL sector of the trucking industry. Trucks do not only serve commercial and industrial establishments but serve private households and construction and maintenance projects as well. The truck-generating capacity of any area within the metropolitan region will therefore depend upon a number of variables which, when identified and interrelated, will yield a measure of the number of truck trips to be expected.

Purely on a theoretical basis, these variables may be identified as population, employment, retail sales and a measure of industrial output. Assuming a positive correlation between the number of trip ends and these variables, and assuming further an outward expansion of their distributional patterns, it is clear that the number of truck trips may likewise be expected to expand in an outward direction.

In trucking transportation, especially where large carriers are used, more than half of the gross revenue is consumed by wages. In turn, more than half of the wage bill goes to personnel operating the vehicles (2). The wage element in the cost structure of trucking transportation therefore becomes extremely sensitive to the time factor which, in the built-up areas, is not only a function of distance, but of traffic controls and traffic congestion as well. Added transportation cost, as expressed in Pigou's concept (3) of the marginal vehicle entering a traffic stream running just under capacity, will not only accrue to the marginal vehicle, but to every other vehicle in the entire traffic stream as well.

Avoiding such routes of heavy traffic concentration relative to available capacity will result in continuously-changing patterns of truck concentration on various arterial routes. These patterns are prone to further changes, due to likely innovations in the methods of truck operation such as further trends toward consolidation of freight and movements toward increased off-peak trucking activity. These changes, however, are not likely to have any important impact upon truck traffic patterns until questions of responsibility in the handling of freight together with problems of labor union regulation have been resolved.

CHAPTER III

AN ANALYTICAL APPROACH TO TERMINAL LOCATION AND TRUCK TRAFFIC PATTERNS

An Analytical Investigation into the Changing Distributional Patterns of Truck Terminals

This phase of the study proposes to evaluate within the framework of an analytical model the interrelationships between the various locational factors which determine the distributional patterns of truck terminals. It also proposes to show how changes in the locational factors tend to change the distributional patterns of truck terminals over a period of time.

Locational Factors

Among the various locational factors which mold the over-all distributional pattern of trucking terminals, the one which identifies the individual sub-patterns more clearly than any of the others is the factor relating to the operational characteristics of common carrier transportation. For the purpose of this investigation and without the danger of excessive digression from reality it suffices to distinguish between only three major forms of common carrier operation: those respectively performed on a local, regional and interregional scale. These three forms of operation identify the three basic sub-patterns of terminal distribution which together give shape to the final pattern.

In its simplest form the transportation of general freight by common carrier consists of three distinct operations. First, the line-haul operation, from a terminal of origin to a terminal of destination. Second, the break-up of freight at the terminal of destination; and, third, the distribution of freight to points of termination within the area of distribution.

In developing a cost function which will determine the optimal location of the individual terminal, the transportation cost variable will therefore vary in accordance with the nature of the operations of the various carriers. For the predominantly local carrier, line-haul cost will be of little, if any, consequence. Emphasis will, rather, be on local pick-up and delivery operations. In contrast, local pick-up and delivery operations may be of only minor importance to the inter-regional carrier, since line-haul operations are his prime concern.

Apart from the transportation cost, the cost function will contain another variable: cost of terminal operation. The essential requirements for any trucking terminal are land, labor and capital.

Land constitutes the primary locational factor for the inputs. It provides space for a terminal building, a maintenance shop, office activities, parking of equipment and parking of private vehicles for employees. Land rent generally decreases in value with increasing distance from areas of concentrated commercial and industrial activity.

As a locational force labor can be considered mobile within the metropolitan area. Substitution between labor and mechanical handling devices in the operation of the terminal is assumed to have negligible effects upon location.

Similarly, capital may also be regarded mobile within the context of this investigation.

The Cost Function

The cost function, which must be minimized for the entire operation, in terms of the optimal location of the individual terminal is of the general form:

$$K = {}_{pd}K + {}_{to}K + {}_{l}K + {}_{tr}K \qquad \ldots\ldots (1)$$

where ${}_{pd}K$ = Pick-up and Delivery Cost

${}_{to}K$ = Terminal Operating Cost

${}_{l}K$ = Line-haul Cost

${}_{tr}K$ = Transshipment Cost

For the purpose of finding an optimal location at which the cost function is minimized, only the variable costs in each individual element of the cost function need be considered.

$${}_{pd}K = \alpha(c,x + a) \qquad \ldots\ldots (2)$$

The pick-up and delivery function is generally performed as a combined operation. The relevant vehicle sets out from the terminal to a specific area where it delivers and picks up freight either by making one run for deliveries and a subsequent run for pick-up's, or completes both operations in a single run (1). The variable portion of the pick-up and delivery cost will therefore be a function of the freight demand (x) in its area of operation and of the cost (c) of transporting a unit of freight to and from this area. The constant cost (a) represents the cost of pick-up and delivery within the area. This will remain constant regardless of where the terminal is located.

$$_{to}K = \beta(X_A, i, p + b) \qquad \ldots\ldots (3)$$

The variable cost of terminal operation will depend in the first instance upon the size of terminal which, in turn, depends upon the volume of freight (X_A) handled. It is furthermore dependent upon the price per unit of land area and the current interest rate. The constant operating cost (b) includes labor, services, buildings, spares and the like.

$$_{l}K = \gamma(X_A, C + d) \qquad \ldots\ldots (4)$$

The line-haul cost includes the entire cost of line-haul between the terminal of origin and the terminal of destination. The variable portion of the line-haul cost may be regarded as the cost of transporting the volume of freight (X_A) between a certain cut-off point near the metropolitan area and the terminal. (C is the minimum cost of transporting a unit of freight from the cut-off point to the terminal within the metropolitan area.) The constant portion of the line-haul cost will then be equal to the cost between the cut-off point and the distant terminal.

$$_{tr}K = \delta(X_{AB}, C) \qquad \ldots\ldots (5)$$

The transshipment cost has no constant portion. It is purely a function of the volume of freight (X_{AB}) to be transshipped between terminals and the minimum cost of transportation (C) per unit of freight.

Revenue is essentially a function of the freight handled and depends directly upon the rate applicable to a particular shipment from its point of origin to its point of destination. Among the wide variety of rates are class and commodity rates, interstate and intrastate rates, LTL and TL rates, local, joint, through and combination rates. For the purpose of this investigation, it is sufficient to consider revenue as a function of the volume of freight and a given rate only.

Then, for the entire operation, the profit function may be expressed as:

$$P = R - (K' + K)$$

$$P = (R - K') - K \qquad \ldots\ldots (6)$$

where R is the total revenue, K' the constant cost of operation and K the variable cost of operation with respect to the location of the terminal. In order to maximize the profit (P), the variable cost (K) must be minimized.

A Model for Determining the Optimal Location of a Trucking Terminal

The first problem is one of developing a method by which a location can be determined which will minimize K. This may be accomplished as follows: Let two common carriers of general freight A and B operate respectively between regions A and B and their respective terminals T_A and T_B within the metropolitan area. Carrier A's freight from region A for region B is transferred from terminal T_A to T_B and vice versa.

In the first part of this investigation, terminal T_B is assumed fixed. It is required to find the optimal location of terminal T_A in terms of minimum cost as expressed by Equation (1). Later the effect upon the location of T_A due to changes in the locational factors will be determined. Finally, the conditions for locating T_A, when T_B is not fixed, is investigated.

The amount of freight hauled from region A to terminal T_A is made up of two portions:

$$X_A = X_{AM} + X_{AB} \qquad \ldots\ldots (7)$$

where

X_{AM} = The portion to be distributed within the metropolitan area by pick-up and delivery trucks operating from terminal T_A.

X_{AB} = The portion to be transferred to T_B by semi-trailer vehicles and hence shipped to region B by carrier B.

Let T = The number of line-haul trucks required to move X_A from region A to T_A.

t = The number of pick-up and delivery trucks to distribute X_{AM} within the metropolitan region.

C_b^a = The cost to transport one unit of freight between points a and b, when using semi-trailer type trucks.

c_b^a = The cost to transport one unit of freight between points a and b, when using pick-up and delivery trucks.

If V = Capacity of the line-haul truck

f_T = Average load factor for the line-haul truck ($\prec 1$)

then $$T = \frac{X_A}{V.f_T}$$

This determines the number of line-haul trucks required. Since this investigation is confined to the transportation of general freight by common carriers, it may be assumed that the same number of trucks will move into the terminal as move out over a given period of time.

Similarly, if v = Capacity of pick-up and delivery trucks

f_t = Average load factor for pick-up and delivery trucks.

then $$t_{ij} = \frac{x_{ij}}{v.f_t}$$

This determines the number of pick-up and delivery trucks required for each pick-up and delivery area which, for the purpose of this investigation, will be termed a "cell."

In its simplest form the metropolitan area may be represented in the form of a rectangular grid, with mn cells. The total transportation demand, X_A, from local sources is known and is such that

$$X_A = x_{11} + x_{12} + \ldots\ldots + x_{ij} + \ldots\ldots + x_{mn}.$$

$$X_A = \sum_{i}^{m} \sum_{j}^{n} x_{ij} \qquad \ldots\ldots \qquad (8)$$

where x_{ij} is the known demand for transportation in any cell, ij, expressed in "units" of freight.

One of these cells will contain the additional demand for interchange freight, X_{AB}. Some of the x_{ij}'s may be zero.

The cost of transportation per unit of freight C_b^a and c_b^a between points a and b, for the large and small trucks respectively, is a function of both distance and time, which in turn are dependent upon the type of highway, terrain, traffic controls and congestion. It is necessary, therefore, that the values of C_{kl}^{ij} and c_{kl}^{ij} between nodes ij and kl be determined separately.

The refinement of picking up large volumes of freight, in certain cells, by semi-trailer rather than by pick-up and delivery truck can be accommodated in the model by expressing the former in terms of equivalent pick-up and delivery trucks.

Figure 1 shows the spatial distribution of cells 11, 12, ...ij,....mn, connected to each other by a rectangular system of transportation links which meet at the center of each cell. It also shows the expressways leading to the metropolitan area from regions A and B, and the connections between the expressways and the local street system.

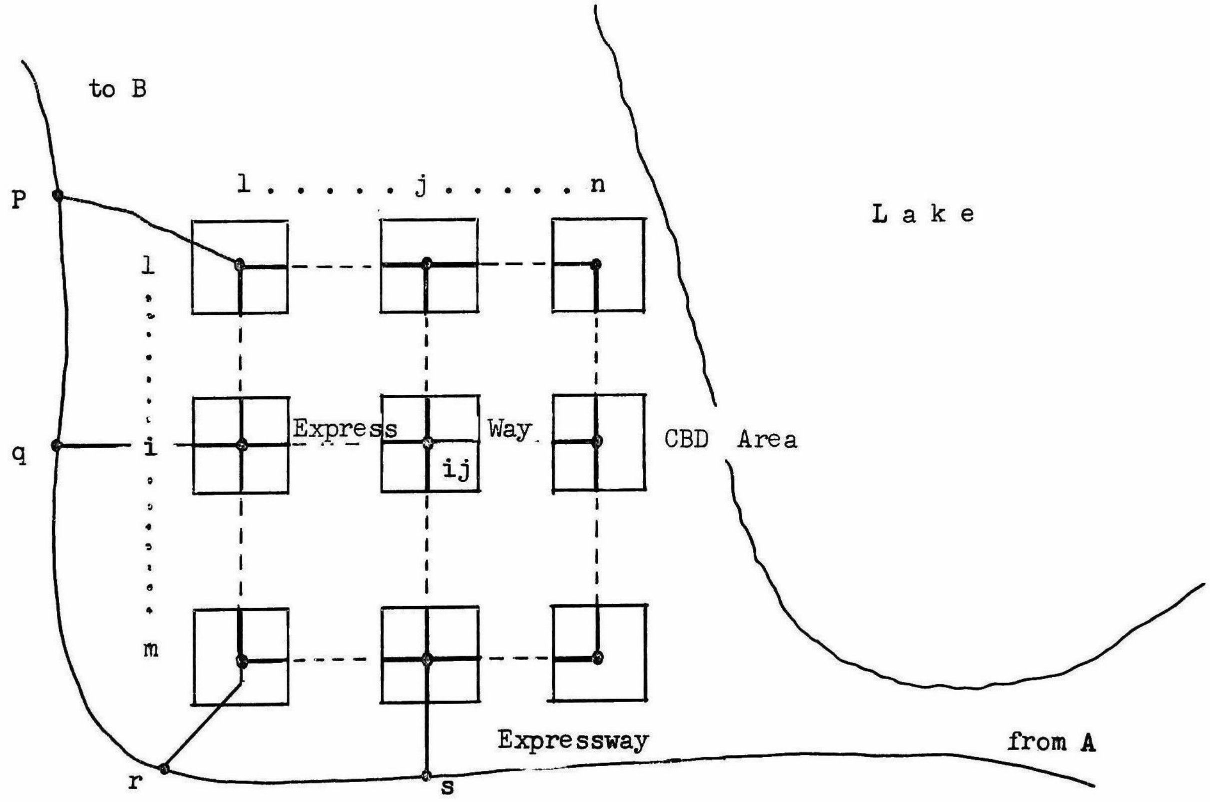


FIGURE 1

CELLS OF HYPOTHETICAL LTL FREIGHT DEMAND

Consider now the individual elements of the cost function.

1. $_{pd}K$: Pick-up and Delivery

In each of the mn cells there is a freight demand of x_{ij} for carrier A. The cost of transportation per unit of freight c^{ij}_{kl} between any two cells, ij and kl, is related to the amount of traffic congestion toward the downtown area and the less restricted flow of traffic on the expressways.

Thus, while $c^{in}_{jn} > c^{jn}_{kn}$ or $c^{hn}_{in} > c^{gn}_{hn}$ the unit cost along an expressway in row i, for instance, may be constant such that

$$c^{il}_{i2} = c^{in-1}_{in} \quad \text{and} \quad c^{in-1}_{in} < c^{in}_{jn}$$

Since the relationship between x_{ij} and t_{ij} is known, x_{ij}, the unit of freight will be used in the further investigation instead of t_{ij}, purely for the purpose of convenience of notation. x_{ij} therefore represents the number of truck trips from cell ij to the terminal which is required to satisfy the demand. In this case c^{ij}_{kl} represents the transportation cost per truck between the two cells ij and kl.

The problem is to find the cell at which the sum of pick-up and delivery costs to all other cells is a minimum.

$$_{pd}K_{kl} = \sum_{i}^{m} \sum_{j}^{n} c^{kl}_{ij} \, x_{ij} \qquad \text{.....} \ (9)$$

where c^{kl}_{ij} is the minimum cost of transportation per unit freight demand between cell kl and any cells ij ($i = 1...m$, $j = 1....n$)

The constant portion of the pick-up and delivery costs is assumed to be the same regardless of where the terminal is located and is consequently disregarded.

The minimum cost of pick-up and delivery to any specific cell can be determined by using the Uncapacitated Transportation Network Model, which is of the general form

$$\text{min. } C(x) = \sum_{i}^{m} \sum_{j}^{n} c_{ij} x_{ij} \qquad \ldots\ldots (10)$$

subject to $\sum_j x_{ij} - \sum_j x_{ji} = a_i$

where $a_i < 0$ denotes an output node

$a_i = 0$ denotes a transshipment node

$a_i > 0$ denotes an input node

also subject to

$x_{ii} = 0$ and $c_{ii} = \infty$

Using the transportation network model for this particular problem and investigating the minimum transportation cost for a terminal in cell kl, then

kl = the input node

All nodes with $x_{ij} = 0$ are transshipment nodes

All nodes with $x_{ij} > 0$ are output nodes.

The use of this model no longer confines the cells and their transportation links to a regular grid pattern, but gives them entire freedom of spatial arrangement.

Each individual cell ij in turn can be regarded as the input node by interchanging the relevant rows and columns in the cost matrix of the network problem. This will produce a final matrix of all ${}_{pd}K_{ij}$'s of the form:

$$\begin{array}{ccccc} {}_{pd}K_{11} & \cdots\cdots & {}_{pd}K_{1j} & \cdots\cdots & {}_{pd}K_{1n} \\ \vdots & & \vdots & & \vdots \\ {}_{pd}K_{i1} & \cdots\cdots & {}_{pd}K_{ij} & \cdots\cdots & {}_{pd}K_{in} \\ \vdots & & \vdots & & \vdots \\ {}_{pd}K_{m1} & \cdots\cdots & {}_{pd}K_{mj} & \cdots\cdots & {}_{pd}K_{mn} \end{array} \qquad \ldots\ldots (11)$$

The cell with a minimum ${}_{pd}K_{ij}$ value will then be selected as the best location for location T_A in terms of pick-up and delivery cost.

Routes barred to truck traffic by municipal regulation are given a large c_{kl}^{ij} value, thus eliminating their use.

2. ${}_{to}K$: Terminal Operating Costs

Assuming mobility of labor and services within the metropolitan area and assuming further that the amount of land required is the same for a given X_A, regardless of location, the variable cost in terminal operation will be land rent. The matrix for land rent may be represented as follows:

$$\begin{array}{ccccc} {}_{to}K_{11} & \cdots\cdots & {}_{to}K_{1j} & \cdots\cdots & {}_{to}K_{1n} \\ \vdots & & \vdots & & \vdots \\ {}_{to}K_{i1} & \cdots\cdots & {}_{to}K_{ij} & \cdots\cdots & {}_{to}K_{in} \\ \vdots & & \vdots & & \vdots \\ {}_{to}K_{m1} & \cdots\cdots & {}_{to}K_{mj} & \cdots\cdots & {}_{to}K_{mn} \end{array} \qquad \ldots\ldots (12)$$

Where the construction of terminals is prohibited by Municipal Zoning Ordinance, the costs of terminal operation theoretically become infinitely large.

3. ${}_1K$: Line-haul Costs

The variable portion of the line-haul costs for carrier A is that portion which starts at point s (see Figure 1). The problem is to find the line-haul costs for quantity X_A to every cell ij (where $i = 1 \ldots m$, $j = 1 \ldots n$). As in the case of the pick-up and delivery costs, the number of trucks, T, will be represented by the quantity X_A, for convenience of notation. The solution to this problem is identical to the solution of the pick-up and delivery problem, except that in this case the cost of unit transportation between nodes ij and kl is C_{kl}^{ij} instead of c_{kl}^{ij}. Here, s is the input node, nodes ij (where $i = 1 \ldots m$, $j = 1 \ldots n$) are all transshipment nodes, except the one which is selected as output node. Also, p, q, and r are transshipment nodes.

The resulting cost matrix for ${}_1K$, the variable line-haul costs, may be presented as follows:

$$\begin{array}{ccccc} {}_1K_{11} & \cdots\cdots & {}_1K_{1j} & \cdots\cdots & {}_1K_{1n} \\ \vdots & & \vdots & & \vdots \\ {}_1K_{i1} & \cdots\cdots & {}_1K_{ij} & \cdots\cdots & {}_1K_{in} \\ \vdots & & \vdots & & \vdots \\ {}_1K_{m1} & \cdots\cdots & {}_1K_{mj} & \cdots\cdots & {}_1K_{mn} \end{array} \qquad \cdots\cdots \ (13)$$

From Figure 1, considering that the transportation costs along the expressway and away from the more congested areas are less than those within the network, it is obvious that the minimum cost of line-haul transportation will occur in one of the cells away from the congested area.

4. ${}_{tr}K$: Transshipment Costs

In this part of the investigation it has been assumed that terminal T_B has already been established and that carrier A is dependent upon the location of this terminal for the location of its own terminal T_A. Thus, it is necessary to find the transshipment cost between the cell containing T_B and every other cell ij. For the purpose of this problem, transshipment is made in semi-trailers only, thus C^{ij}_{kl} will be used as a measure of cost per unit of shipment from cell ij to the terminal cell kl.

The minimum cost of transshipment from any cell ij to cell kl can be determined by the methods outlined previously. The resulting matrix will be of the form:

$$\begin{array}{ccccc} {}_{tr}K_{11} & \cdots\cdots & {}_{tr}K_{1j} & \cdots\cdots & {}_{tr}K_{1n} \\ \vdots & & \vdots & & \vdots \\ {}_{tr}K_{i1} & \cdots\cdots & {}_{tr}K_{ij} & \cdots\cdots & {}_{tr}K_{in} \\ \vdots & & \vdots & & \vdots \\ {}_{tr}K_{m1} & \cdots\cdots & {}_{tr}K_{mj} & \cdots\cdots & {}_{tr}K_{mn} \end{array} \qquad \cdots\cdots \ (14)$$

A similar cost matrix can be produced where the carrier employs piggy-back transportation.

The summation of the four cost matrices will render the total variable costs. The cell with minimum costs will be selected as the one for the optimal terminal location, according to the criterion of minimum cost. (Example I in the appendix illustrates briefly the solution of the transportation network problem as suggested for the three transportation cost variables.)

A single model which will determine meaningful relationships between land rent and transportation costs has thus far not been developed (2).

Some Distributional Patterns

Considering first the purely local carrier, the original cost function reduces to

$$K'' = {}_{pd}K + {}_{to}K \qquad \ldots\ldots\ldots (15)$$

the term for line-haul cost is small and may be disregarded; inter-line freight does not exist.

In the early days of the trucking industry the "terminal" was frequently an old warehouse or garage with relatively low variable cost of terminal operation (${}_{to}K$). These structures were almost ubiquitous. Furthermore, cost of transportation, due to the low concentration of traffic throughout the built-up area, was synonymous with distance, such that the terminal location was determined solely by finding the minimum pick-up and delivery cost in terms of freight and distance traveled. Thus,

$$\text{min. } {}_{pd}K = (x,d) \text{ where d is the distance from the terminal to the cell of demand (x).} \qquad \ldots\ldots\ldots (16)$$

The ideal location was therefore at the "center of gravity" of demand. With orientation almost entirely determined by demand, the resulting pattern of terminals closely followed the pattern of commercial and industrial activity.

With demand increasing faster in the mature commercial and industrial areas than in the outwardly-expanding establishments of this type, the need for larger areas of land and the higher transportation cost within the now more concentrated area of traffic brought into effect two additional locational factors. The desire of the carriers to be close to their shippers was counteracted by high land rent and congestion.

The resulting pattern may be derived from the cost function

$$K' = {}_{pd}K + {}_{to}K + {}_{l}K \qquad \ldots\ldots\ldots (17)$$

where each carrier has his individual pattern of demand and each has a different line-haul cost (due to entering the metropolitan area from different directions).

Following a "typical" radial, the ${}_{pd}K$ cost variable will generally increase with increased distance from the center of commercial and industrial activity while both the ${}_{to}K$ and ${}_{l}K$ cost variables will generally increase in the reverse direction.

For the convenience of notation, let ${}_{pd}K = \alpha K$ and let the sum of ${}_{to}K$ and ${}_{l}K$ be βK.

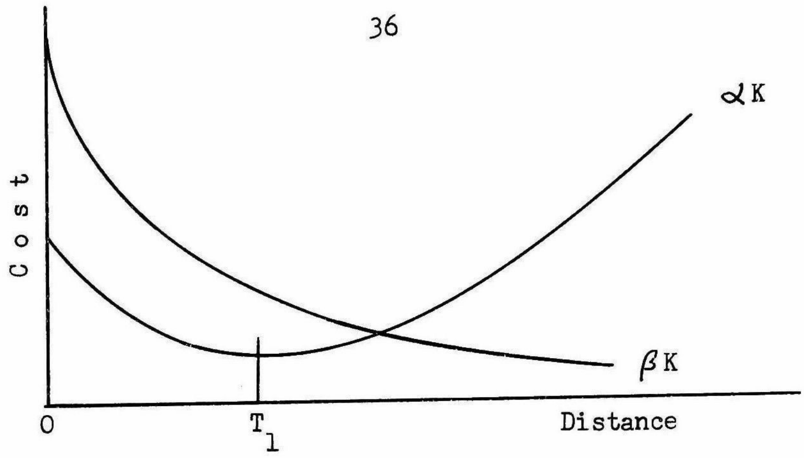


FIGURE 2

HYPOTHETICAL RELATIONSHIP BETWEEN TERMINAL COST ELEMENTS

Let the cost along any radial be presented by two cost curves as shown in Figure 2. Then the point which minimizes the joint cost can be determined by differentiating the cost function.

$$K' = \alpha K \quad (d) + \beta K \quad (d)$$

$$\frac{dK'}{dd} = \frac{\partial \alpha K}{\partial d} + \frac{\partial \beta K}{\partial d}$$

and this function will be a minimum when

$$\frac{\partial \alpha K}{\partial d} = - \frac{\partial \beta K}{\partial d} \qquad \ldots\ldots\ldots (18)$$

i.e., where the marginal costs of the two variables are equal.

The location, therefore, depends upon the relative rate of change of the two variables with respect to the distance from the central area. In keeping the αK cost function constant, it is clear that as the βK function changes from one with $\frac{\partial \beta K}{\partial d} = 0$ i.e., with uniform costs, to one with a negative rate of change with respect to d, $OT_2 > OT_1$, in every case. This means that the terminal will move in an outward direction from the area of concentrated activity. However, the function αK might also change. Since $\alpha K = f(c.x)$ i.e., a function of transportation cost per unit of freight and of demand, both might change simultaneously.

A method for determining how the optimal point of location of a terminal will change with changes in demand at any one or more of the cells is developed below.

Sensitivity Test for ${}_{pd}K$: Pick-up and Delivery Costs

The problem may be stated briefly as follows: Given the sum of minimum pick-up and delivery costs from all cells in a network to any specific cell, what minimum amount of freight demand must be added to any specific cell in order to move the terminal out of the original cell when all costs are held constant.

It was shown previously how the minimum pick-up and delivery cost can be determined at any cell ij in the matrix mn and how these costs can be arrayed in matrix form. The minimum cost per unit of transportation between any two nodes can be presented in another form as follows.

		11	12	ef		ij	kl	mn
x_{11}	11							
x_{12}	12	c^{12}_{11}						
x_{ef}	ef							
x_{ij}	ij			c^{ij}_{ef}			c^{ij}_{kl}	c^{ij}_{mn}
x_{kl}	kl					c^{kl}_{ij}		
x_{mn}	mn			c^{mn}_{ef}				
${}_{pd}K_{ij}$				${}_{pd}K_{ef}$		${}_{pd}K_{ij}$		${}_{pk}K_{mn}$

FIGURE 3

PICK-UP AND DELIVERY COSTS BETWEEN ANY PAIR OF CELLS

In the foregoing cost matrix

x_{ij} = Total freight demand in cell ij.

c^{ij}_{mn} = Minimum cost of transportation per unit freight from cell ij to cell mn.

$$_{pd}K_{kl} = x_{11}\cdot c^{11}_{kl} + x_{12}\cdot c^{12}_{kl} + \ldots\ldots + x_{ij}\cdot c^{ij}_{kl} + \ldots\ldots\ldots\ x_{mn}c^{mn}_{kl}$$

$$= \sum_{i}^{m}\sum_{j}^{n} x_{ij}c^{ij}_{kl} \qquad \ldots\ldots\ldots (19)$$

which represents the total cost of pick-up and delivery for the terminal located in cell kl.

Let kl be the cell in which $_{pd}K_{kl}$ is a minimum. This will be the optimal location for terminal T_A when considering pick-up and delivery costs only.

Case I. What is the least amount of additional demand in the cell of second least cost, which will move the terminal from its cell of minimum cost, kl, to that cell?

Let the cell of second least cost be ef.

The difference in the total cost between cells ef and kl is

$$\Delta\, _{pd}K^{ef}_{kl} = {}_{pd}K_{ef} - {}_{pd}K_{kl}$$

and the difference in the cost per unit of freight between these two cells is

$$\Delta c^{ef}_{kl} = c^{ef}_{kl} - c^{ef}_{ef}$$

However, since the cost within any cell is zero, by definition ($c^{ef}_{ef} = 0$), the additional freight demand in cell ef, in order to move the terminal from kl to ef will be

$$x_{ef} > \frac{_{pd}K_{ef} - {}_{pd}K_{kl}}{c^{ef}_{kl} - c^{ef}_{ef}}$$

or

$$x_{ef} \geq \frac{\Delta_{pd}K^{ef}_{kl}}{\Delta c^{ef}_{kl}} \qquad \ldots\ldots\ldots (20)$$

Thus, if the freight demand at ef, the cell of second least cost, exceeds the difference of the total cost between this cell and the cell of least cost, per minimum cost per unit of freight between the two relevant cells ef and kl, then the terminal will move from kl to ef.

<u>Case II.</u> How does an increase greater than Δx_{ef} at any of the other nodes affect the location of the terminal?

The terminal will move to cell ef, the cell of the second least cost, not only with an additional increase of Δx_{ef} in cell ef, but may do so with an additional increase Δx_{mn} at any other cell mn, provided that

$$\Delta c^{mn}_{kl} = c^{mn}_{kl} - c^{mn}_{ef} \geq 0$$

then

$$\Delta x_{mn} > \frac{pd^K{}_{ef} - pd^K{}_{kl}}{c^{mn}_{kl} - c^{mn}_{ef}} \qquad \ldots\ldots\ldots (21)$$

This means where the additional freight demand at kl or at mn is respectively greater than Δx_{ef} or Δx_{mn} the terminal will move to cell ef. If, however, a quantity $\Delta x'_{ef}$ is added to x_{ef} at ef where $\frac{\Delta x'_{ef}}{\Delta x_{ef}} < 1$, then the minimum quantity $\Delta x'_{mn}$ to be added to x_{mn} at mn, in order move the terminal from its original position kl to cell ef can be determined as follows:

$$\Delta K^{ef}_{kl} = {}_{pd}K_{ef} - {}_{pd}K_{kl}$$

Using $\Delta x'_{ef}$ instead of Δx_{ef} will make

$$\Delta K'^{ef}_{kl} = ({}_{pd}K_{ef} + c^{ef}_{kl} \ \Delta x'_{ef}) - ({}_{pd}K_{kl} + c^{ef}_{ef} \ \Delta x'_{ef})$$

$$= {}_{pd}K_{ef} - {}_{pd}K_{kl} + c^{ef}_{kl} \ \Delta x'_{ef} \quad \text{since } c^{ef}_{ef} \ \Delta x'_{ef} = 0$$

$$= \Delta K^{ef}_{kl} + \Delta x'_{ef} \ c^{ef}_{kl}$$

Then

$$\Delta x'_{mn} \geq \frac{\Delta K^{ef}_{kl} - \Delta x'_{ef} \ c^{ef}_{kl}}{c^{mn}_{kl} - c^{mn}_{ef}}$$

$$\Delta x'_{mn} \geq \frac{\Delta K'^{kl}_{ef}}{c^{mn}_{kl} - c^{mn}_{ef}} \qquad \ldots\ldots\ldots (22)$$

Thus, in all cells where the cost per unit of pick-up and delivery freight between the cell and the cell of second least cost is greater than that between the cell and the cell of least cost, a calculable amount of additional freight demand will move the terminal to the cell of original second least cost, from the cell of original least cost. The former will now be the cell of least cost. If less than the minimum amount is added to any one of the cells, then the minimum amount to be added in the other cells can be calculated.

<u>Case III.</u> By how much would x_{lm} have to be increased at any cell lm, or at any other cell or cells before the terminal will move to lm?

This case is equivalent to the case where the amount of transshipment freight between two terminals increases so much that it becomes less costly for the "independent" terminal to move to the cell of the "dependent" terminal.

In this case it is necessary to determine the value of

$$\Delta K^{ij}_{lm} = K_{lm} - K_{ij} \qquad \text{for all values of ij.}$$

Also, since $c^{lm}_{lm} = 0$

$$\Delta x_{lm} > \frac{K_{lm} - K_{ij}}{c^{lm}_{ij}} \qquad \text{for all ij's} \qquad \ldots\ldots\ (23)$$

The maximum Δx_{lm} value will give the minimum additional freight demand which needs to be added to x_{lm} for the terminal to move from its original location at kl to lm.

If the amount of increase $\Delta x'_{lm} < \Delta x_{lm}$, then by using the method previously mentioned, the minimum additional $\Delta x'_{ij}$ at any cell ij can be determined.

Also, if the Δx_{ij}'s are ranked in magnitude from the smallest to the largest, then any Δx_{ij} will cause the terminal to move to any of the cells with a $\Delta x_{i'j'} < \Delta x_{ij}$. The minimum cost will be incurred, however, at the cell of second least cost.

Although this section of the investigation deals with the sensitivity of the ${}_{pd}K$ cost variable, the identical reasoning applied to the ${}_{tr}K$ variable, the transshipment cost. The only difference is that when additional demand for freight at any cell ij involves transshipment, the cost C^{ij}_{kl} rather than cost c^{ij}_{kl} would be used. (Those pick-up and delivery trucks performing transshipment functions may be expressed in semi-trailer equivalents.)

If terminal operating cost is taken into account, holding line-haul costs and transshipment costs constant for a while, then it is possible to find the minimum amount of additional freight demand at any cell in order to move the terminal to any other cell. Taking, for example, the case where it is required to find by how much the freight demand must increase in the cell of second least cost in order to have the terminal move to that cell:

Let kl be the cell with the minimum ${}_{pd+to}K$, and ef the cell with the second least ${}_{pd+to}K$, then

$$
\begin{aligned}
{}_{pd+to}\Delta K_{kl}^{ef} &= {}_{pd+to}K_{ef} - {}_{pd+to}K_{kl} \\
&= ({}_{pd}K_{ef} + {}_{to}K_{ef}) - ({}_{pd}K_{kl} + {}_{to}K_{kl}) \\
&= ({}_{pd}K_{ef} - {}_{pd}K_{kl}) + ({}_{to}K_{ef} - {}_{to}K_{kl}) \\
{}_{pd+to}K_{kl}^{ef} &= \Delta\,{}_{pd}K_{kl}^{ef} + \Delta\,{}_{to}K_{kl}^{ef}
\end{aligned}
$$

$$
\text{and}\quad \Delta x_{kl} \geq \frac{{}_{pd+to}\Delta K_{kl}^{ef}}{c_{kl}^{ef}} \qquad (\text{Let } \Delta x_{kl} = \Delta\,{}_{to}x_{kl} + \Delta\,{}_{pd}x_{kl})
$$

where either $\Delta\,{}_{pd}K_{kl}^{ef}$ or $\Delta\,{}_{to}K_{kl}^{ef}$ may be positive or negative.

Thus, if both these terms are positive, then the additional freight demand, due to the higher land rent, is

$$\Delta_{to}x_{kl} > \frac{\Delta_{to}K_{kl}^{ef}}{c_{ef}^{kl}} \qquad \ldots\ldots\ldots (24)$$

i.e., directly proportional
to the difference in land rent
at the two cells ef and kl.

Similarly, by adding the line-haul cost to each cell, the minimum amount of additional freight which will induce the terminal to move can be determined. The three cost differentials will rarely all be positive at the same time. In general, when the difference between pick-up and delivery costs is positive, the difference in corresponding land rent and line-haul costs can be expected to be negative.

The relationship between the relative values of the cost variables and the variation of the value of each individual variable from cell to cell will therefore have an important bearing upon the relocation of a terminal, given a constant expected increase in interchange freight, or the expected future distribution pattern of the shippers.

Example II in the appendix illustrates the foregoing relationships.

Further Distributional Patterns

The pattern for the conditions of uniform unit transportation and land rent costs has already been established. It follows essentially the pattern of commercial and industrial activity.

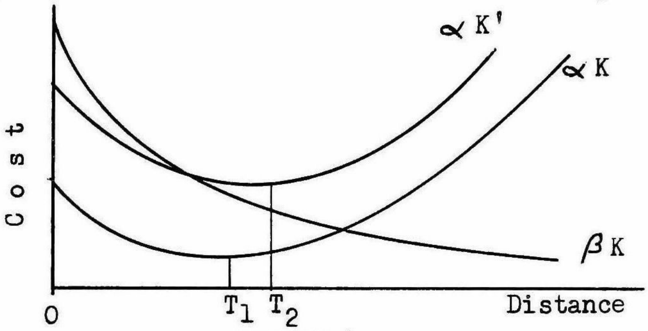


FIGURE 4

EFFECTS OF CHANGE IN HYPOTHETICAL TRANSPORTATION ON ELEMENTS

By the nature of the pick-up and delivery cost function, the rates of change with distance and the minimum point of the relevant curve are theoretically indeterminate, when holding land rent and line-haul cost constant. Any positive change in either the unit cost of transportation between cells or the demand for transportation in any cell, within the area of concentrated activity, will move the curve αK to a new position $\alpha K'$. See Figure 4.

Only when the demand increases in a direction away from 0, in such quantities as can be determined on the basis of the foregoing investigation, will a trend of the minimum point away from 0 become effective. This trend will always be encouraged by both the land rent and the line-haul cost curve βK (due to its negative slope).

The pattern which develops under these conditions is one which might be expected in metropolitan areas which do not constitute a major focal point in the highway transportation network. The carriers with low line-haul cost and only minimal terminal requirements, due to the small scale of their operations will be located predominantly toward their shippers. Those whose operations extend into the regions further afield and having more extensive operations with resulting larger terminal area requirements will tend to move out, preferably to locations along those routes which facilitate ease of line-haul movement.

There still remains a third pattern to be superimposed on the two previous ones. The one brought about by a further function of the terminal: the handling of inter-line freight. This pattern is brought out in an investigation of the location of two terminals for conditions where they are located either dependently or independently of one another.

The Optimal Location of Two Trucking Terminals

Assume carriers A and B to operate between regions A and B respectively and their respective terminals, T_A and T_B within the metropolitan area. The problem is to find an optimal location for T_A and T_B under several alternative conditions.

Condition 1. There is no interchange of freight between terminals T_A and T_B.

Under these circumstances and in accordance with the minimum cost criterion, A will always locate in cell kl where

$$ {}^{a}K'_{kl} = {}^{a}_{pd}K_{kl} + {}^{a}_{to}K_{kl} + {}^{a}_{l}K_{kl} \qquad \ldots\ldots\ldots \quad (25) $$

is a minimum for all ${}^{a}K_{ij}$'s.

Similarly, B will locate in the cell where the cost is minimum.

The methods for determining these cells have already been discussed. Since both the demand pattern and line-haul cost pattern will be different for the two carriers (the land-rent pattern will be the same), they are likely to find their minimum cost of operation in different cells.

It has also been shown how the minimum amount of Δx_{ij} can be determined, as a function of the difference between the total minimum costs and the difference between the transportation costs between any two cells.

Thus, where the amount of interchange freight between two terminals is zero, or Δx_{ij} is small, they will be located independently of each other. In the absence of constraints such as municipal regulation, a wide spatial distribution of terminals, with primary function of handling the pick-up and delivery freight, can be expected.

Condition 2. Interchange of freight between terminals T_A and T_B is such that Δx_{kl}, the additional (interchange) freight at T_A in cell kl, is greater than the minimum required for T_B to move out of cell ef.

a. In order for carrier A to minimize his costs, he will always locate at T_A, in cell kl, where ${}^aK_{kl}$ is the minimum cost of operation, provided that T_B is located in the same cell, thus making ${}^a_{tr}K_{kl} = 0$. The same reasoning applies to carrier B, with regard to his location in cell ef.

b. In the case where A is already firmly established at T_A, in cell kl, carrier B will locate such that

$$ {}^bK_{ij} = {}^b_{pd}K_{ij} + {}^b_{to}K_{ij} + {}^b_{l}K_{ij} + {}^b_{tr}K_{ij} \qquad \ldots\ldots\ldots (26)$$

is a minimum, moving from its original cell ef to cell ij, due to an additional minimum demand Δx_{kl} at kl where

$$ \underset{\text{min.}}{\Delta} x_{kl} > \frac{{}^bK_{ij} - {}^bK_{ef}}{C^{kl}_{ef} - C^{kl}_{ij}} \qquad \ldots\ldots\ldots (27)$$

and ij is the cell of second least cost. T_B will only move to cell kl when

$$ \underset{\text{max.}}{\Delta} x_{kl} > \frac{{}^bK_{kl} - {}^bK_{ij}}{C^{kl}_{ij}} \qquad \ldots\ldots\ldots (28)$$

where Δx_{kl} is the minimum of all ij's.

An intermediary amount of freight, between Δx_{kl} min. and Δx_{kl} max. will move the terminal T_B to any cell lm provided that

$$C^{kl}_{ef} - C^{kl}_{lm} > 0$$

i.e., provided that the unit cost from cell lm to cell kl is less than that from cell ef to cell kl. This suggests a trend of terminal T_B toward terminal T_A. The cell which carrier B will ultimately select for his terminal T_B will depend upon the value of Δx_{kl}.

c. Where T_B is not located at cell kl, the cell in which T_A is located, carrier A will also incur additional costs due to the interchange of freight between T_A and T_B. One way of solving this problem is to minimize the sum of the operational costs of carriers A and B, thus

$$\text{minimize} \quad {}^{a}K_{ij} + {}^{b}K_{ij}$$

Let gk be the cell in which the sum of the variable costs is a minimum. In this cell both ${}^{a}_{tr}K^{gk}_{gk}$ and ${}^{b}_{tr}K^{gk}_{gk}$ are equal to zero. The only question remaining is how much interchange freight must there be between T_A and T_B before both will move to a common point gk.

$${}^{b}\Delta x_{gk} > \frac{{}^{b}K_{gk} - {}^{b}K_{ij}}{C^{gk}_{ij}}$$

similarly, $${}^{a}\Delta x_{gk} > \frac{{}^{a}K_{gk} - {}^{a}K_{ij}}{C^{gk}_{ij}} \qquad \ldots\ldots\ldots (29)$$

where ij is the cell giving max. ${}^{b}\Delta x_{gk}$ and max. ${}^{a}\Delta x_{gk}$, respectively.

The greater of these two values will give the minimum amount of interchange freight necessary in order that both terminals move to a common point.

The Final Locational Pattern

Where two terminals are dependent upon another, both with their own distinctive pattern of demand within the metropolitan area, the amount of interchange freight between these two terminals, which will cause them to locate in a common cell, can be determined. Since the cost of transshipment becomes zero in the common cell, the quantity of interchange freight required can be readily determined.

The amount of interchange freight depends upon the pattern of interregional trade and upon the regulatory controls on carriers in the areas which they are permitted to serve. Any major nodal point in the regional transportation network will, under the present system of ICC regulation, have a substantial amount of inter-line freight. As trade increases between the various regions, the trend toward agglomeration of terminals can be expected to increase. Also, since large volumes of freight will be interchanged between terminals by semi-trailer type vehicles, the agglomeration of carriers may be expected to tend toward location near major traffic arterials with relatively unrestricted flow. The increased use of piggy-backing is more likely to influence the locational patterns of the regional carrier with predominantly local shippers than those of the interregional shippers.

Thus, superimposed upon the previous two patterns of trucking terminals is a third pattern, consisting mainly of large carriers handling a high proportion of inter-line freight.

The patterns will not be clear-cut in practice. Overlapping and inconsistencies will occur within the metropolitan area. For one, in spite of reasonable prognostications of future demand and of the spatial distribution of this demand, the response to changes in the locational factors has not always been immediate. The lag has been due to one or more of several factors such as the cost of relocation, the uncertainty of the time of completion of projected public works programs in the field of highway construction, the uncertainty of the impact of certain technological innovations such as piggyback or containerization, the indecision of the carrier in his policy with regard to mergers with other carriers or acquisition of these and the uncertainty of the future plans on relocation of other carriers.

Some of the constraints which cause the lag in relocation or even the more forceful ones which prohibit the location of terminals in certain areas can conveniently be incorporated in the foregoing formulation. This was shown in the case where the additional demand which would move the terminal from its original cell of minimum cost to another cell was determined on the basis of both pick-up and delivery cost and terminal operation cost. The latter might well include a constant for the cost of relocating the terminal. Where municipal zoning regulations prohibit the construction of terminals in certain areas, it is only necessary to give the terminal operating cost an unproportional high value, in the terminal cost matrix, in order to keep the terminal out of any particular cell.

While constraints on such factors as policy decisions cannot be incorporated in any model for determining the optimal location of a terminal, even less intangible ones are often difficult to include. For instance, the cost of unit transportation between two cells when applied to a local carrier may have completely different values when applied to the interregional operator. In the latter case a penalty cost might have to be added to some of the routes used by pick-up and delivery trucks, as well as to some of those used by line-haul vehicles. A late departure from the metropolitan area of a line-haul vehicle, due to delayed arrivals of pick-up and delivery trucks at the terminal (with the alternative of forfeiting a certain volume of freight) or due to adverse traffic conditions encountered by the line-haul vehicle, may result in wasted hours along the line by relay drivers and may also delay the stripping of the vehicle at the terminal of destination by an entire day.

An Analytic Investigation into the Changing Distributional Patterns of Truck Trips

Truck trips are attracted to all parts of the metropolitan area and serve a wide variety of functions. Residential areas require trucks for the delivery of goods, the performance of services and for construction and maintenance purposes. Commercial and industrial areas require trucks for the transportation of goods and materials, and likewise for the performance of services, construction and maintenance.

From this it follows that the pattern of truck trips will change, not only with changes in land use, but also with changes in the intensity of its activity. It will, furthermore, change with changes in traffic concentration as related to the available capacity of the roadways.

For this reason it becomes necessary, therefore, to examine the truck trip patterns from two aspects: first, the pattern of truck trip ends and, secondly, the pattern of truck traffic flow.

Pattern of Truck Trip Ends

In the various studies which have been made on trip generation, emphasis has always been on person trips, more in particular on the generation of automobile trips. This is quite understandable, since automobile trips generally account for the far greater proportion of vehicle trips in the traffic pattern. The studies which have actually been done on truck trip generation are usually confined to special cases as, for instance, determining the number of truck trips which is generated by a specific acreage of a narrowly-defined land use.

In seeking a formulation which will explain changes in truck trip generation, it is first necessary to determine the number of truck trips which will satisfy the transportation demands in any area within the metropolitan region in terms of a number of variables which must be identified and interrelated.

Within a framework of appropriate zones, into which the metropolitan region may be divided, two types of truck trips will be examined separately: intra-zone truck trips and inter-zone truck trips.

Intra-zone Truck Trips

Intra-zone truck trips are essentially short trips. These are generally under-reported in O-D surveys. In consequence, the formulation of an interrelationship between these trips and the various variables may lose some accuracy.

One of the very few studies (3) hitherto undertaken on over-all truck trip generation indicates that the following relationship gives a reasonable correlation between intra-zone truck trips and the pertinent variables expressed in terms of dwelling units, employment and retail sales:

$$T = aD + bE + cR + k \qquad \ldots\ldots\ (30)$$

where T = number of intra-zone trips
D = number of dwelling units
E = number of employees
a, b, c = regression coefficients
k = constant

The constant k relates to the total number of dwelling units and takes care of those zones which do not have many residents such as the more predominantly commercial and industrial zones.

Inter-zone Trips

The same study also contains a relationship between inter-zone trips and various dependent variables which are identified as employment, retail sales, population and land use. In its general form:

$$T' = dE + eR + fP + K \qquad \ldots\ldots\ (31)$$

where T' = number of inter-zone trips
E = number of employees
R = per cent of region's retail sales in zone
d, e, f = regression coefficients
K = a constant relating to intensity of land use

It is obvious that in the final analysis a considerable amount of refinement in the variables is possible, such as considering different groups of employment or different income categories. For the purpose of determining the changing patterns of truck trip ends, it suffices to identify and relate the major generating forces, viz., employment, retail sales, population and some measure of output (whether this be industrial output or, for instance, the output of a trucking terminal).

Since the multi-correlation equations are generally developed on current data, a projection of truck trip ends based upon expected values of the dependent variables will, in the final evaluation, require additional considerations such as technological improvements in surface transportation and freight handling devices and in trends which might be prevalent in handling techniques of freight (4).

Pattern of Inter-zone Trips

In the previous section it was shown how the total number of truck trip ends may be determined for any zone and how expected changes in the dependent variables may cause corresponding changes in the distributional pattern of truck trip ends. However, a knowledge of truck trip patterns is incomplete without an understanding of those forces which attract truck traffic between zones and of those factors which create retarding effects upon such forces of attraction.

A great deal of research has been done on the problems of traffic assignment, and many theoretical models have been suggested for predicting traffic flows between cities and other traffic generators. Several of these models have been programmed for computers and have been used in transportation planning projects (5). In most of these models, truck traffic was given only little attention. Truck traffic was either included in the total traffic flow, or it was neglected entirely.

The two general types of models which help to explain the changes in the patterns of traffic flow are discussed briefly in this section.

The first model assumes the current number of trips generated in any zone as given and the distribution of trips between zones as known. The problem is to distribute future trips between zones when the future number of trips in each zone is known.

Let T_i, T_j, T_k, T_l be the number of current truck trips in the four zones i, j, k, and l, and let t_{ij} be the current number of truck trips between i and j. (See Figure 5) If T'_i is the expected number of truck trips in zone i, during some future year, and $\frac{T'_i}{T_i} = G_i$ is defined as the growth factor of zone i, then the number of future trips t'_{ij} from zone i to zone j is given by

$$t'_{ij} = \frac{T'_i \cdot t_{ij} \cdot G_j}{t_{ij}\cdot G_j + t_{ik}\cdot G_k + t_{il}\cdot G_l}$$

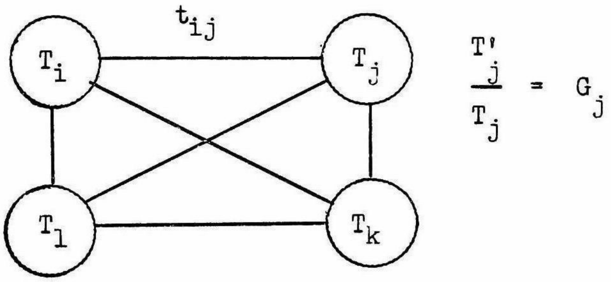


FIGURE 5

ARRANGEMENT OF CELLS FOR ILLUSTRATING "FRATAR" METHOD

Similarly, the value of t'_{ji} can be determined and by successive approximations, adjusting for the values of G, the final traffic flows between the four zones calculated.

This method used by Fratar (6) in Cleveland was adapted for use in Detroit by Carrol (7) such that the value of t'_{ij} could be determined as follows:

$$t'_{ij} = \frac{t_{ij} . G_i . G_j}{G} \qquad \text{.......} \; (33)$$

where G is the total growth factor and the other symbols have the same connotation as the symbols in the previous equation.

Both of these methods rely entirely upon existing traffic flows and upon growth factors. The force of attraction is the absolute number of interregional trips generated in any zone. One apparent shortcoming in adapting this general model to truck traffic is its disregard for intra-regional trips. This is partly solved in the gravity model.

In more recent years much research has been done on the gravity model (8), which is of the general form

$$t_{ij} = \frac{P_i P_j}{f(s_{ij})} \qquad \text{.......} \; (34)$$

where t_{ij} = the number of trips between zones i and j

P_i, P_j = "forces of attraction" in zones i and j

s_{ij} = a quantity which relates in some way to the distance or time of travel between zones i and j

The function $f(s_{ij})$ is commonly of the form s^x where x may have some positive value, depending on the type of trip considered.

This method thus postulates a certain "pulling power" of possible destinations and a certain "friction" in getting to the destination.

No special model has yet been evolved for truck trips, although many refinements have been added to the model for person trips, such as the introduction of the cost element by Tanner (9) and Wardrop (10).

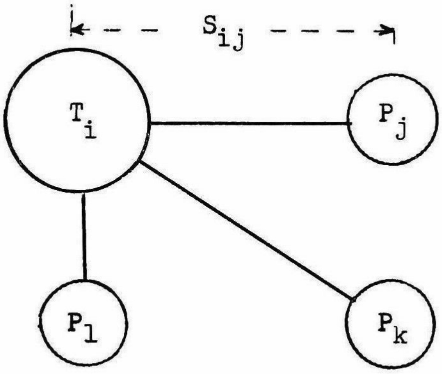


FIGURE 6

ARRANGEMENT OF CELLS FOR ILLUSTRATING "GRAVITY MODEL" CONCEPT

Thus, where T_i is the total number of trips generated in zone i and P_j, P_k and P_l are "forces of attraction" in zones j, k and l respectively (see Figure 6), the number of trips between zone i and j can be expressed as

$$t_{ij} = \frac{T_i \cdot \frac{P_j}{s_j^x}}{\frac{P_j}{s_{ij}^x} + \frac{P_k}{s_{ik}^x} + \frac{P_l}{s_{il}^x}} \qquad \ldots\ldots\ (35)$$

In this expression use is made of both distance and time. The nature of P and the magnitude of x varies with the type of trip.

In the previous model it was seen that the number of trips between any two zones were assumed to be in proportion to the number of inter-zone trips generated by the individual zones. Applying a similar assumption to the general version of the gravity model as stated above, the P values may simply be replaced by T values. In the previous section, the value of T was expressed by the following relationship: T = f(Population, Employment, Retail Sales and Output). By using T instead of any single dependent variable (P = population is frequently used), the gravity approach can be expected to yield an entirely reasonable prediction of inter-zone truck trips at different periods of time. The value of x can only be determined by empirical methods.

Only two of some six methods for determining travel patterns between zones have been mentioned here. Considerable controversy still exists as to the merits of each one, and research is presently being conducted to test their relative merits (11). One feature which they do have in common is the agreement that size and distribution of population together with concentration of commercial and industrial activity ultimately determine travel patterns.

CHAPTER IV

CHANGES IN TRUCK TERMINAL DISTRIBUTION PATTERNS: 1950-1960 IN THE METROPOLITAN AREA OF CHICAGO

By virtue of its function as a point of breakup, consolidation and transfer of LTL shipments, the truck terminal is a nodal point for common carrier operations. An analysis of the pattern of truck terminals and of the resulting pattern of truck traffic will therefore emphasize the common carrier sector rather than identify the entire picture of trucking operations.

Every common carrier serving a metropolitan area has a terminal point in that area to and from which its line-haul and pick-up and delivery vehicles operate. Terminal points vary widely in size and character. Physically they may range from a large terminal owned and operated solely by an individual carrier to a small terminal building within a terminal area operated jointly by several carriers. For this reason the distribution of terminal "points" rather than that of terminal structures will form the basis of this investigation. The term "terminal" when used in the context of this study will therefore imply "point of termination," regardless of its physical and operational properties.

Although the total number of common carriers of general freight with terminals in the metropolitan area of Chicago increased by only 5 per cent, from 515 to 544, during the decade 1950-1960 (1), a considerable movement in their spatial distribution was evidenced.

The investigation of the changes resulting from this movement has been based on the areal subdivisions as defined by "Districts" in the Chicago Area Transportation Study (2). This was done primarily for the convenience of comparing changes in the distributional patterns of truck terminals to those in other elements of metropolitan activity such as employment, trip ends, warehouses, industries and population. Figure 7 shows the spatial arrangement of CATS "Districts," illustrating each of two typical "Rings," "Sectors," and "Districts."

The first section of this investigation deals with the general distribution of truck terminals during the years 1950 and 1960. This is followed by a more detailed analysis of the 1960 distributional pattern, by class of carrier and by permanency of location. Then follows an investigation into the relationship between the changes in truck terminal patterns and those of other activities. Finally, an appraisal is made of the validity and accuracy of the theoretical and analytic approaches in terms of the findings produced in this empirical investigation.

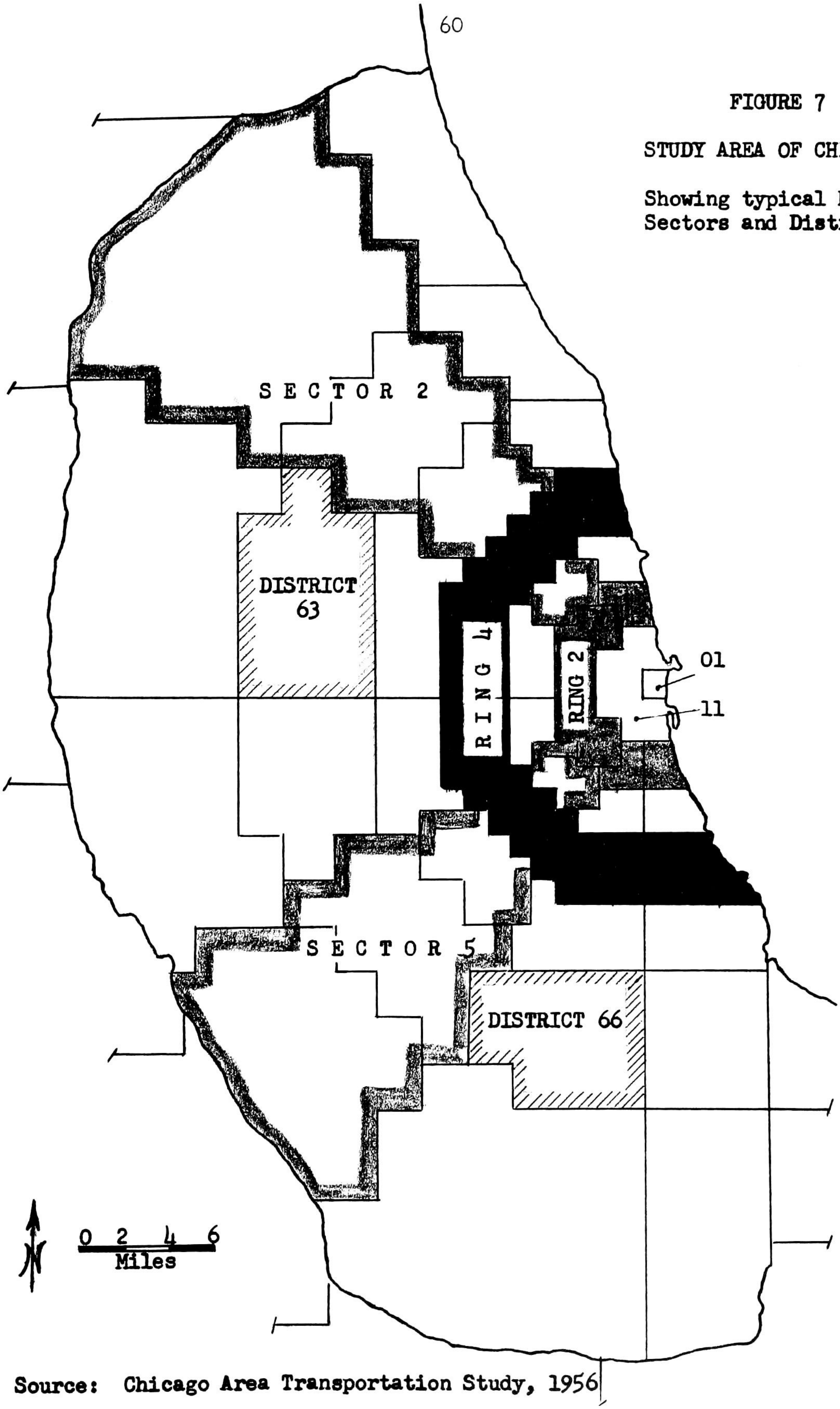
General Distributional Patterns of Truck Terminals: 1950 and 1960.

The distributional pattern of truck terminals within the study area is shown in Figure 8. The upper digit denotes the number of terminals in each district for 1960, while the lower digit denotes the corresponding number of terminals for 1950. The principal features of the two superimposed distributional patterns are brought out more clearly in Table 1, which summarizes the relative frequency distribution of the terminals, by ring and sector. (See Tables i and ii in

FIGURE 7

STUDY AREA OF CHICAGO

Showing typical Rings, Sectors and Districts



Source: Chicago Area Transportation Study, 1956

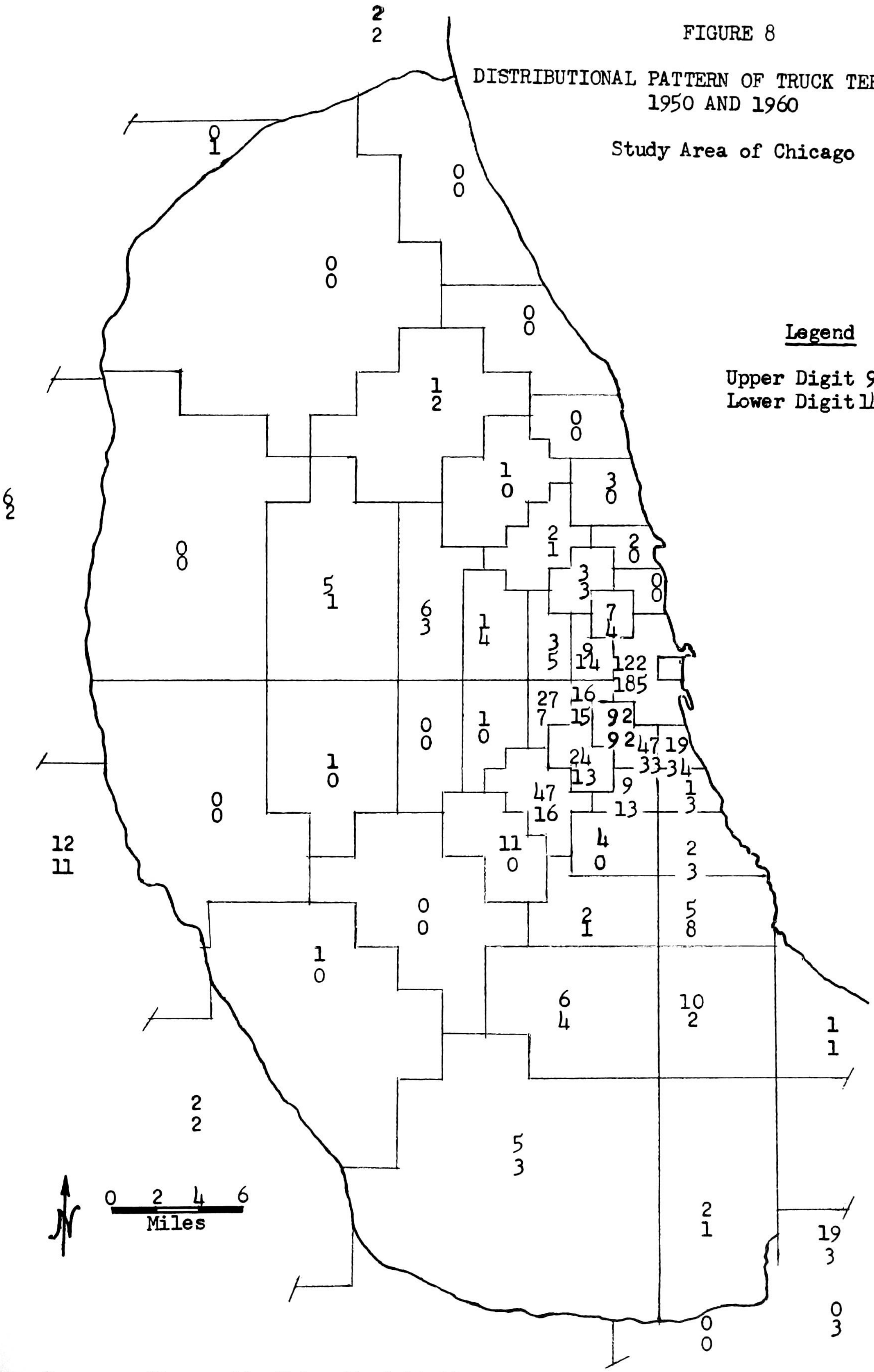
FIGURE 8

DISTRIBUTIONAL PATTERN OF TRUCK TERMINALS 1950 AND 1960

Study Area of Chicago

Legend

Upper Digit 9: 1960
Lower Digit 14: 1950



Source: "Leonard's Motor Freight Directory for Chicago," 1950 and 1960.

the appendix for a more detailed presentation of these data.)

TABLE 1

GENERAL DISTRIBUTION OF TRUCK TERMINALS: 1950 AND 1960

Metropolitan Area of Chicago

Area of Location	Radius (Approx.)	1950	1960
Rings 1 and 2	Less than 4.5 miles	77.0%	57.3%
3 and 4	4.5 - 9.5 miles	13.3%	23.7%
5 and 6	9.5 -18.5 miles	4.2%	9.0%
Beyond Ring 6	More than 18.5 miles	5.5%	10.0%
Sectors 1 to 3		12.7%	12.8%
4 and 5		48.2%	55.7%
6 to 8		39.1%	31.5%
Total Number of Terminals		541	544

The general pattern shows a high concentration of truck terminals toward the core area, decreasing in an outward direction. The predominant feature of change in this pattern over the past decade has been a net outward movement from the core area.

- Table 1 shows that the high concentration of terminals is confined to an area bounded by a 4.5 mile radius from State and Madison Streets. This high concentration decreased from 77.0% in 1950 to 57.3% in 1960. Although the corresponding increase was greatest in the neighboring ring of 5 mile width, where the relative proportion increased from 13.3% to 23.3% during the past decade, the relative increase in the remaining areas nevertheless constitutes an important element in the trend toward outward growth as will be borne out in the more detailed investigation to follow.

The radial distributional pattern of truck terminals shows the highest concentration in the southwestern and southern sectors of the metropolitan region. During the past decade, increases in concentration have occured in the southwestern sectors at the expense of a decrease in the southern sectors. The relatively sparse concentration of truck terminals in the northern sectors has remained almost constant.

- During the decade 1950-1960, the relative number of terminals increased from 48.2% to 55.7% in the southwestern sectors (4 and 5) and decreased from 39.1% to 31.5% in the southern sectors (6 to 8). It remained almost constant, at 12.7% and 12.8% during the respective years, in the area to the north of Harrison Street.

In Figure 9 is shown the frequency distribution of the percentages of terminals in the various rings and sectors for the years 1950 and 1960.

The Distributional Pattern of Truck Terminals by Class of Carrier: 1960

Due to a change during the decade 1950-1960 in the fiscal limits which define each of the three classes of carriers, a comparison between their respective distributional patterns over the ten-year period is not possible. However, an investigation of the distributional patterns of terminals for the three classes of carriers for the year 1960 will, nevertheless, help to explain the more pertinent features of the general pattern. Of the total number of common carriers with terminals in the metropolitan area, two-fifths are Class I, one-fifth is Class II, and two-fifths are Class III carriers (3). Their respective numbers are 222, 110 and 212.

Since the distributional pattern of Class II carriers generally follows a "mean" pattern between the two extreme classes, emphasis in this investigation will be on the existing pattern of the two latter classes.

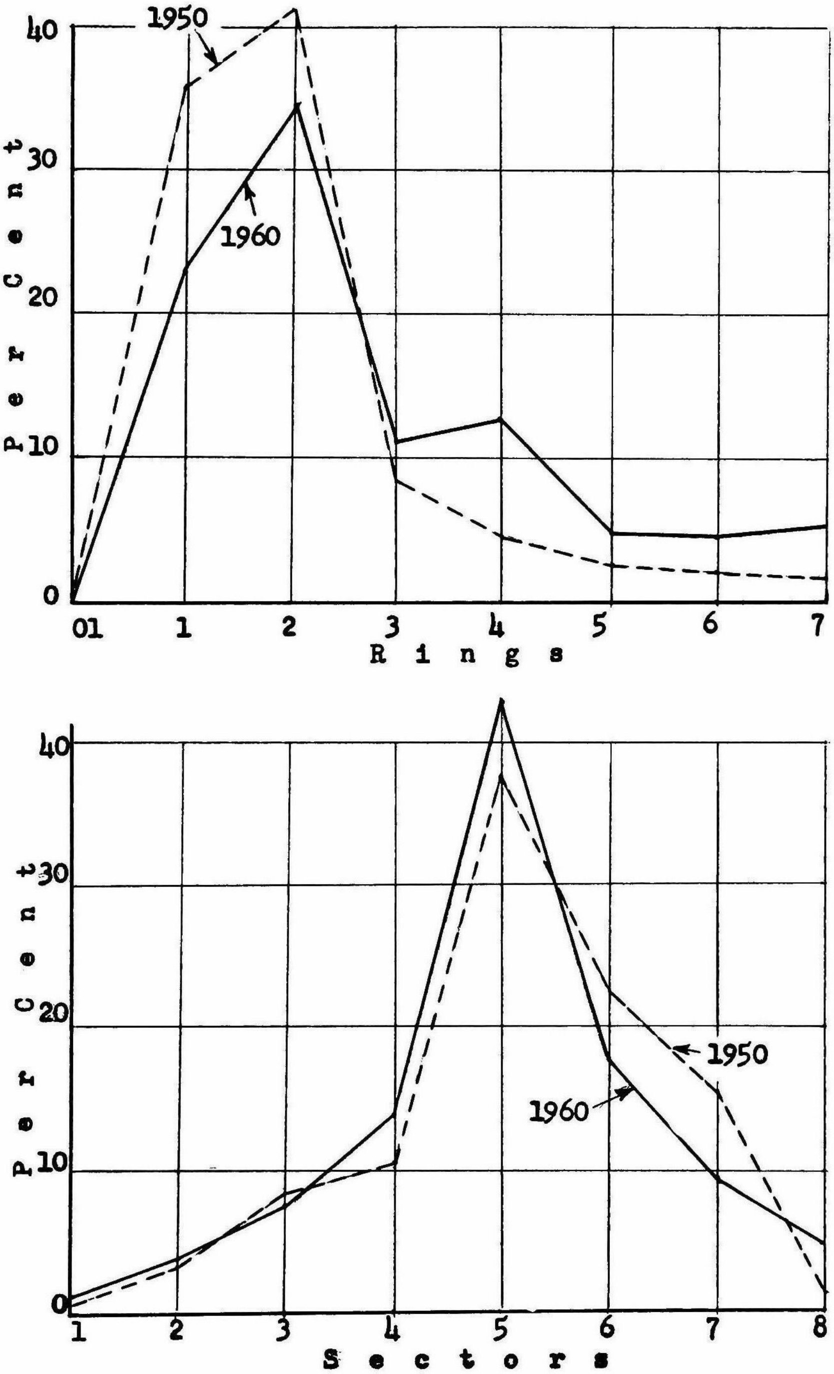


FIGURE 9

RELATIVE DISTRIBUTION OF COMMON CARRIER TRUCK TERMINALS
Metropolitan Area of Chicago

Source: See Tables (i) and (ii) in Appendix.

In Table 2 the percentage distribution by ring and sector is summarized for the terminals of Class I, II and III carriers. (Tables iii, iv, and v in the appendix give a more detailed breakdown.)

TABLE 2

DISTRIBUTION OF TERMINALS BY CLASS OF CARRIER: 1960

Metropolitan Area of Chicago

Area of Location	Radius (Approx.)	Class I	Class II	Class III
Ring 1	Less than 1.5 miles	14.9%	23.9%	29.8%
Ring 2	1.5 - 4.5 miles	36.9%	40.9%	29.8%
Rings 3 and 4	4.5 - 9.5 miles	33.8%	18.2%	15.9%
Beyond Ring 5	More than 9.5 miles	14.4%	17.3%	24.5%
Sectors 1 to 3		2.5%	10.7%	26.8%
4 and 5		65.1%	54.7%	44.3%
6 to 8		32.3%	34.6%	28.9%
Total Number of Carriers		222	110	212

The concentric pattern of distribution shows that Class III carriers are more evenly distributed throughout the study area than Class I carriers. The two striking features of the two respective patterns are, first, the relative concentration of Class III carriers is double that of Class I carriers in the core area; second, the relative concentration of Class III carriers is also substantially higher than that of Class I carriers in areas beyond the city limits.

> Table 2 shows that, while 14.9% of all Class I carriers have terminals within a 1.5 mile radius from State and Madison Streets, the corresponding value for Class III carriers is 29.8%. Also, only 14.4% of all Class I carriers have terminals in an area beyond the city limits, while the corresponding value for Class III carriers is 24.5%. The implications of this peculiarity in the distributional pattern of the two extreme classes will be explained in a subsequent section.

The radial pattern of distribution, as the concentric pattern, shows a more even distribution of Class III carrier terminals than of Class I carrier terminals. It emphasizes the high relative concentration of Class I carriers in the southwestern sectors and the negligible relative concentration of these carriers in the northern and northwestern sectors.

> • From Table 2 it will be observed that in the northern and northwestern sectors (the entire area north of Harrison Street) the proportion of Class I carriers is only 2.6% as compared to 26.8% Class III carriers. In the southwestern sectors (4 and 5) the respective proportions are 65.1% and 44.3%, while in the southern sectors they are more equal with respective values of 32.2% and 28.9%.

The values given in Table 2 furthermore show how the terminal pattern of Class II carriers generally follows the mean terminal pattern of the other two carriers, particularly when considering that the number of Class II carriers is only half that of either of the other two classes.

The Distributional Pattern of Truck Terminals According to Permanency

Of the 544 common carriers with terminals in the metropolitan area of Chicago, only one quarter retained their terminal address of 1950 by 1960. The remainder were either newcomers to the area or had changed their address. The respective proportions of carriers with no address in 1950, no change of address since 1950 and a change in address since 1950 were 32%, 26% and 42% respectively. These proportions point toward the dynamic growth and change both in the trucking industry and in the physical structure of the metropolis.

A summary of the percentage distribution of carriers, by ring and sector, according to the permanency of location is given in Table 3. (A more detailed breakdown of these data is shown in Tables vi, vii, and viii which appear in the appendix.)

TABLE 3

DISTRIBUTION OF TERMINALS BY PERMANENCY OF LOCATION

Metropolitan Area of Chicago

Area of Location	Radius (Approx.)	No Address in 1950	No Change in Address	Change in Address
Rings 1 and 2	Less than 4.5 miles	54.0%	67.2%	53.9%
3 and 4	4.5 - 9.5 miles	17.8%	17.1%	32.2%
5 and 6	9.5 -18.5 miles	13.2%	6.4%	7.4%
Beyond Ring 6	More than 18.5 miles	15.0%	9.3%	6.5%
Sectors 1 to 3		15.6%	17.2%	8.5%
4 and 5		46.6%	47.5%	66.5%
6 to 8		37.8%	35.3%	25.0%
Total Number of Carriers		174	140	230

Although more than one-half of the newcomers to the metropolitan area still preferred locations in close proximity to the core area, the proportion of the carriers who located beyond the city limits is substantially higher than that of those who merely changed their address. Unfortunately, it is not possible to establish the size of carriers who established themselves in the area as newcomers. A fair assumption would be that those who located toward the core were the smaller carriers taking over existing vacated terminals, while those who located on the outskirts were of the larger category.

It is furthermore almost surprising that some two-thirds of the carriers who did not change their address during the decade 1950-1960 are to be found near the central area, while more than one-half of the carriers who changed their address during the same period are presently located in the same area.

- Table 3 shows that while 28.2% of all newcomers located their terminals beyond the city limits, only 13.9% of the carriers who changed their terminal location during the decade 1950-1960 are found in this area presently. It also shows that 67.2% of the carriers who did not change their address are still located within an area of 4.5 miles from State and Madison Streets, while 53.9% of those who changed their address are in that same area.

In the radial pattern both the newcomers and those who did not change their address had a distribution similar to the one found for the general pattern. However, the category of carriers who changed their address is presently found to be located more predominantly in the southwestern sectors.

- From Table 3 it will be observed that 66.5% of the carriers who changed their address during the past decade are presently located in the southwestern sectors (4 and 5).

The three foregoing sections of this investigation may be briefly summarized as follows:

The essential change in the general pattern is one of net outward movement from the core area, with the highest relative gain in concentration in the band immediately adjoining this area. The less spectacular relative gains in the outlying area show interesting trends which will be examined later. The radial pattern shows that the sectors of highest concentration were also the sectors of greatest increase.

The distributional pattern by class of carrier indicates a relatively uniform distribution of the smaller carriers throughout the entire area, while the larger carriers are concentrated predominantly in the southwestern sectors.

One of the outstanding features of the general pattern is its extreme fluidity. More stability in the pattern is foreseen in the future, particularly with the advent of increasing numbers of truck terminal areas.

The Pattern of Truck Terminals as Related to Other Metropolitan Activities

The question now arises: How have changes in other activities within the metropolitan area affected the changing pattern of truck terminals over the past decade? In the theory on terminal location changes in such factors as demand for LTL transportation, traffic congestion and land rent, together with the constraints of municipal zoning, were assumed to have an important bearing upon the changing pattern of terminals. These and related factors will be investigated in this section.

Earlier in this chapter it was shown that the predominant change in the pattern of truck terminals was in an outward direction. This study will therefore be confined essentially to the concentration of the various factors and changes in their concentration by concentric area extending outward from the Loop. In doing so, it is important not to lose the sense of proportion or of perspective. The sense of proportion, insofar as the rings are not all of the same width, might be because the relationship between their areas is not fixed. Differences between their mean radii vary. (Rings 2, 3 and 4 are generally two miles wide, rings 4 and 5 are three miles wide, and ring 6 is six miles wide.) The sense of perspective, insofar as the area of concentrated activity is very small as compared to the entire study area. Considering the area bounded by the outer boundary of ring 5, this area constitutes a little less than one quarter of the total metropolitan study area, defining very approximately the city limits of Chicago (except in the southern sectors where the boundary extends into ring 7).

Since the demand for LTL transportation within the metropolitan area is primarily generated by commercial and industrial establishments (and by other terminals) a relationship between the spatial distribution of truck terminals and that of commercial and industrial land use or activity might be expected to exist. Also, as a measure of economic activity, employment and truck trip ends might be expected to show some relationship to the pattern of truck terminals within any of the concentric areas. Almost surprisingly, no such general relationship seems to exist.

This is evident from Figure 10 which shows the percentage of manufacturing and commercial land in use (2), total truck trip ends (4) and employment (5) by rings and by sectors. (See Tables ix, x, xi and xii in the appendix for a more detailed presentation of these data.) It also shows the percentage of truck terminals in the corresponding rings and sectors. The fact that different years were used in presenting the various patterns does not distract from the validity of the final conclusion that no immediate relationship exists between the truck terminal pattern and the general pattern of the other elements.

Clearly the highest concentration of terminals occurs in ring 2, while that of commercial land and truck trip ends is found further out, in ring 4. The highest proportion of manufacturing land in use

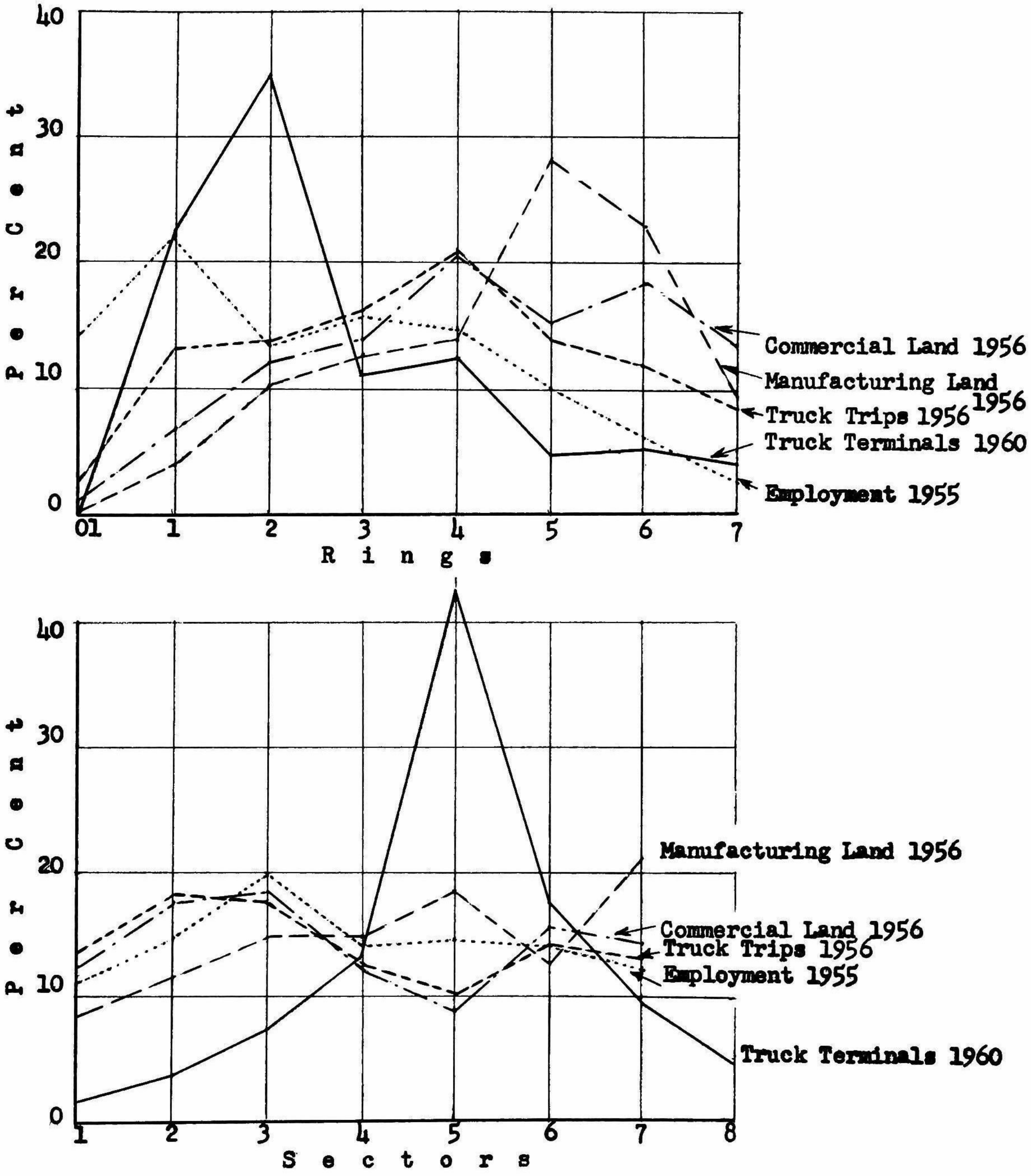


FIGURE 10

RELATIVE FREQUENCY DISTRIBUTION OF TRUCK TERMINALS, MANUFACTURING AND COMMERCIAL LAND, TRUCK TRIP ENDS AND EMPLOYMENT

Metropolitan Area of Chicago

Source: See Tables (i), (ix), (x), (xi), and (xii) in the Appendix.

is shown to be still further out, in ring 5.

Due to the almost reverse pattern of concentration of truck terminals in relation to the patterns of the other elements, when taken by sector, an investigation of the likely relationships, taking an individual sector or group of sectors at a time, proved to be equally negative.

The one important feature brought out by the presentation in Figure 10 is the evident lag in the concentric distributional pattern of truck terminals relative to commercial and manufacturing land concentrations and to the concentration of truck trip ends. This lag is not confined to the static pattern of distribution but is equally discernible in the patterns of change. Only two representative elements have been selected to illustrate this phenomenon: employment and plant location.

In Figure 11 the net changes in employment (5) and in plant relocation (5) as compared to the net changes in the truck terminal pattern are illustrated. (See Tables xii, xiii, and xiv in the appendix for a more detailed breakdown of these data.) It is evident from Figure 11 that both employment and plant relocations had their maximum increases in areas more remote from the core area than those of truck terminals which had their maximum growth in ring 4.

The same phenomenon is brought out in other studies (5) concerning the cost aspect of changes in the metropolitan area. They show, for instance, that the cost of warehouse expansion and the cost of plant relocation was at a distinct maximum in ring 5 during the decade 1950-1960. (See Tables xiii and xv in the appendix for further details.)

There are several factors which help to explain the apparent lack of relationship between the pattern of truck terminals and those

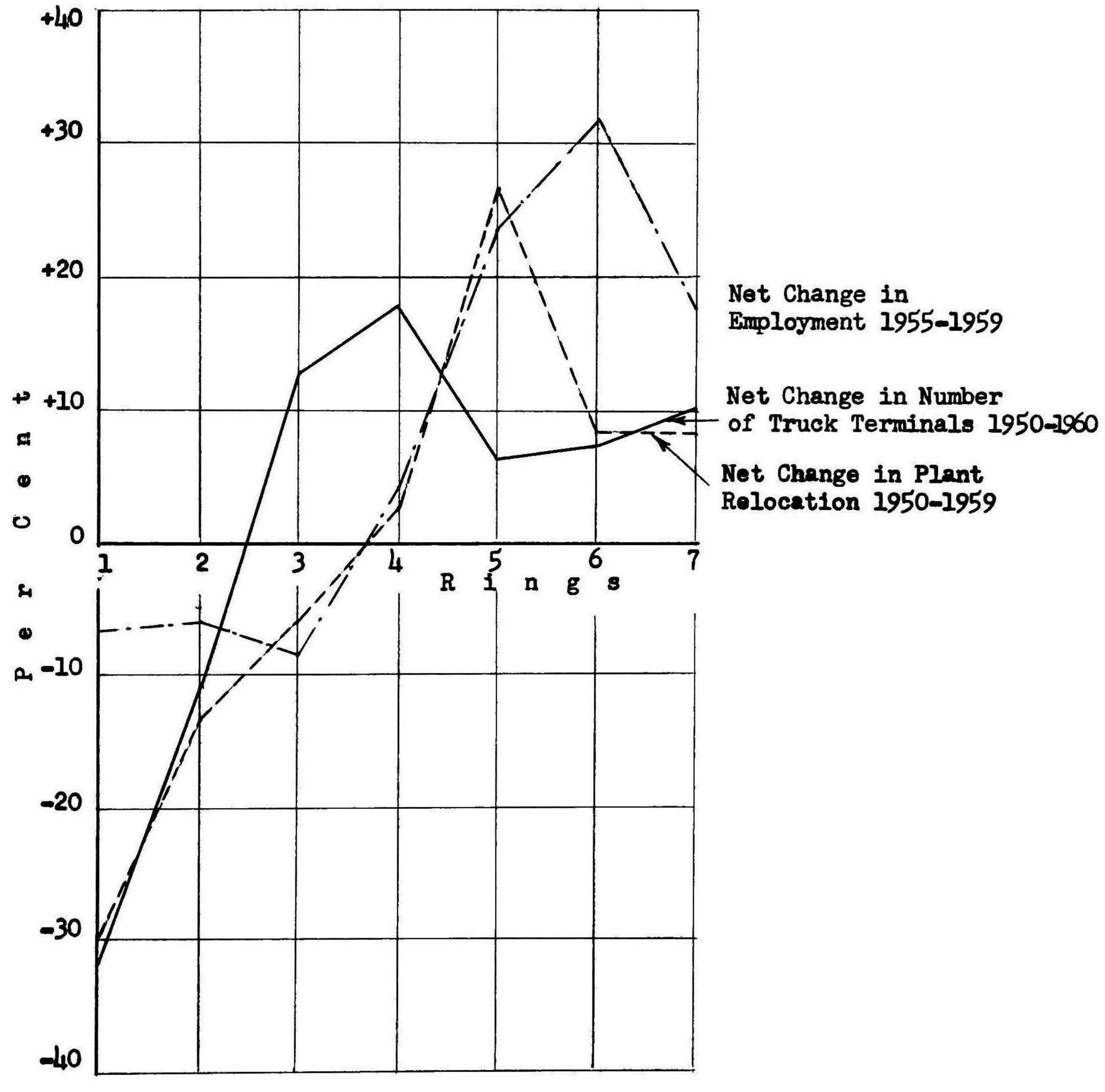


FIGURE 11
NET RELATIVE CHANGES IN TRUCK TERMINAL LOCATION, EMPLOYMENT AND PLANT RELOCATION

Metropolitan Area of Chicago

Source: See Tables (xii), (xiii), and (xiv) in the Appendix.

of the various other elements.

First, the truck trip end pattern is somewhat deceptive, if presented in terms of relative frequencies or even absolute values. A more meaningful picture is gained when trip ends are expressed in terms of density as shown in the following table.

TABLE 4

TOTAL TRUCK TRIP ENDS PER SQUARE MILE (4)

Metropolitan Area of Chicago

	Area	Density
	01	18,300
	11	8,750
	2	4,300
(Ring)	3	3,220
	4	2,040
	5	900
	6	330
	7	103

Thus, while the pattern of terminals is not related to the pattern of truck trip ends per se, the repulsive effect of an area with a high concentration of truck traffic is clearly indicated.

Second, it was seen that the current truck terminal pattern has its highest concentration in ring 2, while the patterns of the other elements generally had their's in rings 4 or 5. Considering the mean distance between the center of these rings, which is 4.5 miles and 7.5 miles between ring 2 and rings 4 and 5 respectively, and considering further the extreme versatility of the truck as a medium of transportation, it is clear that factors other than the demand pattern may have a stronger influence on changing the pattern of truck terminals -- this, in particular, when it is realized that a great many industries, as well as certain commercial concerns, rely also on forms of transportation other than that by common carrier, including private and contract trucking.

Finally, the one element which does have a positive relation to the truck terminal pattern is municipal zoning regulation. The first concrete proposals toward this type of control came from the Committee of Motor Truck Terminals in 1950. In its final report the Committee introduced the concept of truck terminal areas, as distinguished from union terminals, in which each carrier may have his own terminal building, but where services may be shared. It was not until July 1, 1957, however, that the first C-4 Truck Terminal Zones were established by City Ordinance.

By 1959 thirteen such zones, varying widely in size and shape, had been established within the city limits of Chicago. Their spatial distribution is as shown in Table 5.

The striking feature of the distribution is the predominance of terminal areas in the southwestern sector (Sector 5). This is clearly in strong agreement with the heavy concentration of truck terminals in that sector as seen from Figure 9.

TABLE 5

DISTRIBUTION OF C-4 TRUCK TERMINAL AREAS (6)
City of Chicago, 1959

Ring	Sector	Number of Areas
1	1	1
2	5	4
3	5	2
4	5	4
6	7	2

Not all of these areas are fully occupied yet. Naturally, many were zoned because of the already heavy concentration of truck terminals present; others were zoned on considerations of availability of reasonably priced land and of their proximity to some major city or state transportation arterial. The search for additional terminal areas continues as evidenced by the Truck Terminal Survey completed by the Chicago Plan Commission in 1960. One of the objectives of this survey was to establish further C-4 zones within the framework of a new master land use plan for the city.

Since the "Commercial Zone," as defined by the Interstate Commerce Commission, extends beyond the city limits of Chicago, the location of terminals within the metropolitan area is not confined to C-4 zones in the city. These zones obviously do not always meet the needs of the individual carrier, particularly those of the large carrier who requires more space than may be available and who may, in addition, wish to be closer to the major traffic routes. Indeed, the maximum increase in the proportion of terminals in ring 4, as shown in Figure 11, took place in that portion of ring 4 which lies beyond the city boundary.

With passing years the pattern of terminal location within the city limits can be expected to follow increasingly the pattern of C-4 zones as terminals presently in use and frequently conflicting in land use are disbanded in favor of locations more suitable to the carrier.

In summary, apart from a trend away from areas of high traffic concentration and a remote relationship to economic output as measured by the number of employees, the pattern of truck terminals is influenced most strongly by municipal zoning regulation. This, together with the versatility of the truck, helps to explain the lag between the outward movement of terminals and that of the many other elements which contribute to the functioning of the metropolis.

An Appraisal of the Theoretical and Analytical Approaches in Terms of Actual Findings

Both the theoretical and analytical approaches provide a good starting point from which the forces which are responsible for changes in truck terminal patterns can be identified and explained. Several inconsistencies appear, however, when comparing the postulated patterns with the existing pattern of truck terminals.

In the theory on truck terminal distribution, three patterns were postulated on the basis of three different time periods: the period of the individual operator, the period of growth, and the period of consolidation.

The pattern of truck terminals as it exists today shows that the period of consolidation has now been reached. Relics of the two previous periods, however, still remain.

The major features of inconsistency in the theoretical and actual patterns are the following. First, the relatively high concentration of Class I carriers close to the core area. According to the theory, Class I carriers would be expected to be located much farther out. This inconsistency is perhaps best explained by the element of inertia prevalent in the adjustment of the truck terminal pattern to a set of new conditions. Most present major expressways within the metropolitan area were only completed during the last quarter of the study period and have not yet had sufficient time to develop their full influence upon terminal location. An outward move, furthermore, generally involves construction with higher capital outlays as opposed to the less costly practice of taking over an existing terminal. Also, greater dependence of inter-line carriers on one another, coupled with the uncertainty as to the future plans of others, has resulted in some hesitation in the individual carrier as regards his otherwise desirable move to an outward location. This all leads to the conclusion that the period of consolidation, while already in progress, has not yet reached its final stage.

Second, the high concentration of Class III carriers relative to Class I carriers in the areas beyond the limits of the city is not consistent with the theory. This is explained by the peculiarity of the metropolitan structure with its core city and satellite cities around it. Some of the latter cities are sufficiently large to have their own truck terminals. Among these are Aurora, Hammond and Gary.

Third, the relatively high proportion of new addresses close to the core area may be explained by the presumption that new carriers, particularly the smaller ones, will frequently move into existing terminal buildings which have been vacated by others.

In the analytical approach three sub-patterns of terminals were identified according to local, regional and interregional carrier operation. In adapting the transportation network model to determine the optimal location of a terminal, it was assumed that demand for LTL transportation was independent of supply. This obviously is not entirely the case. For this reason substitution of inter-line freight for local freight was suggested for the large carrier in moving his terminal away from the main concentration of local shippers. In practice, however, there is a limit to this type of substitution. The joint freight rate frequently used for inter-line shipments produces a lesser share of revenue than does the direct freight rate to the local shipper. There is thus a minimum amount of local freight which must be handled by each carrier in order to make his operations sufficiently rewarding. The locational effect of the joint freight rate is one which encourages orientation toward the expressway system and more especially so toward the radials running toward the areas of concentrated economic activity.

In the analytical approach it was also assumed that capital is mobile. In practice this is not entirely the case. Generally capital is more readily available for a new terminal to be constructed in proximity to other terminals than for the individually-located terminals. The capital element of the cost structure thus has a tendency to encourage agglomeration of truck terminals.

The evaluation of an optimal location for a truck terminal when using the adapted transportation network model appears prohibitive when considering the large number of possible points of location. In effect, municipal regulation on the location of truck terminals imposes a sufficient constraint to make this model feasible.

This constraint, whereby terminal areas are zoned by the Municipal Planning Authority, within the framework of the over-all land use plan, is likely to have the greatest single influence upon the truck terminal pattern of the future.

CHAPTER V

CHANGES IN TRUCK TRAFFIC PATTERNS: 1950-1956 IN THE METROPOLITAN AREA OF CHICAGO

Existing Pattern of Truck Trips

Only on rare occasions has the truck received its proper due in metropolitan transportation projects. There are two apparent reasons for this. First, the number of trucks registered is relatively small. Second, the patterns of truck and automobile trips are sufficiently alike to suggest that no special treatment for trucks will be warranted in locating new highways (1). Though plausible, these reasons are not entirely valid.

- In 1956, some 1,341,600 automobiles and 130,000 trucks were registered in the Metropolitan Area of Chicago. However, although truck registrations accounted for only 8.2% of all vehicles registered (including taxis and automobiles owned by private industry and governmental agencies), they were responsible for 13.9% of all trips.

Considering further that the larger types of trucks are frequently restricted to certain major routes and barred from others, it is clear that the prevailing thinking on intra-metropolitan and intra-city freight movement by truck needs some revision, particularly when related to transportation planning.

A comparison between the relative distribution of truck trips and trips performed by all vehicles on the basis of distances from the core area shows a much higher proportion of truck trips in the inner areas of more intense concentrated activity.

- This observation is substantiated in Table 6 which shows that almost 30% of all truck trips are made within a 4.5 mile radius from State and Madison Streets, while less than 20% of all trips are made in this area. (A more detailed presentation of the data given in Table 6 is contained in Tables xi and xvi in the appendix.)

The relatively higher concentration of truck trips toward the core area is even more accentuated when truck trips are expressed in terms of equivalent automobile trips (for purposes of street and intersection capacity considerations) and when taking into account that the techniques used in the Chicago Area Transportation Study did not allow for intra-block truck trips.

TABLE 6

RELATIVE DISTRIBUTION OF TRIPS: 1956

Metropolitan Area of Chicago

Ring	All Trucks (%)	All Vehicles (%)
01	2.65	2.42
11	13.09	6.98
2	13.61	9.42
3	16.02	13.67
4	20.89	22.38
5	14.02	17.19
6	11.67	16.25
7	8.05	11.69
	100.00	100.00

- Expressing the 130,242 truck trips, within a 1.5 mile radius from the center of the core area, as equivalent automobile trips by applying a factor as low as 2, the resulting 260,484 equivalent automobile trips represent a sizeable proportion of the total number of trips, considering that 428,833 regular automobile and taxi trips are made in the same area.

The relative distribution of trips by concentric rings is deceptive as regards the concentration of trips. Although the relative number of truck trips is small in the core area, the density is nevertheless extremely high.

- As shown in Table 4, the core area has 18,300 truck trips per square mile per day, as contrasted to only 2,040 truck trips per square mile per day in the concentric area 6.0 to 9.5 miles from State and Madison Streets.

Trips performed by heavy trucks constitute only a small portion of the total number of truck trips. Their concentric distributional pattern is almost constant throughout, except for the inner core in which their use is restricted.

- The share of truck trips by light, medium and heavy trucks was 36.7%, 55.2% and 8.1% respectively.

Perhaps more important than the concentric distributional pattern is the radial distributional pattern of truck trips as shown in Figure 12. This pattern for light- and medium-size trucks is exactly the reverse of that for truck terminal distribution, suggesting that with current pick-up and delivery methods a change in the pattern of truck terminals cannot be expected to exercise any important influence on the radial distributional trip pattern of light- and medium-size trucks. Obviously there are other forces which determine this pattern and its changes. These will be investigated shortly. In contrast, the radial pattern of distribution for heavy trucks shows a peak, though less pronounced, in the southwestern sector in a similar manner as the radial pattern of truck terminals. This might infer that a change in the pattern of truck terminal distribution could influence the small segment of heavy trucks which, nevertheless, constitutes an important ingredient of the traffic stream.

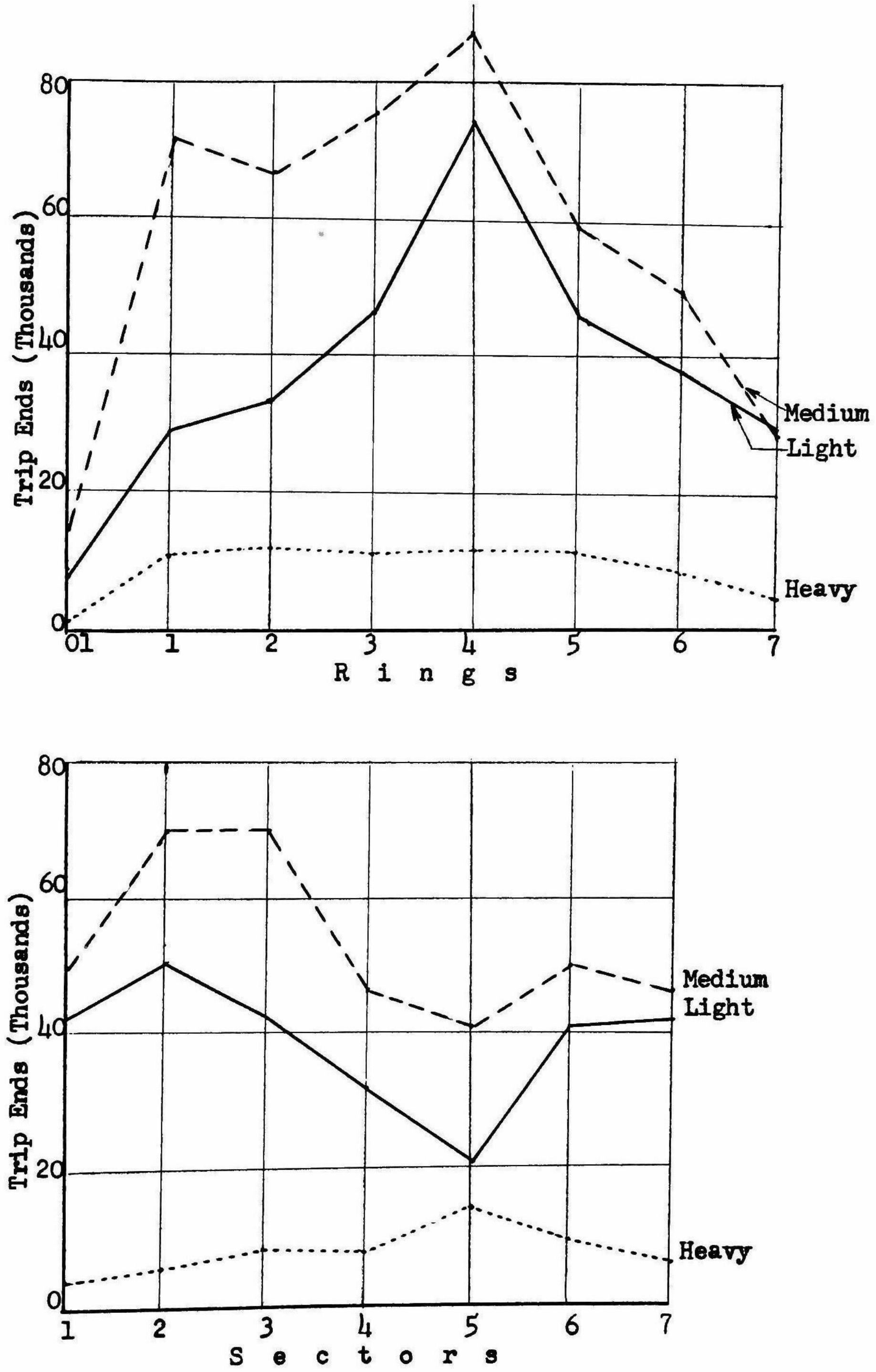


FIGURE 12
DISTRIBUTION OF LIGHT, MEDIUM AND HEAVY TRUCK TRIP ENDS
Metropolitan Area of Chicago 1956

Source: See Table (xi) in Appendix.

Factors in Truck Trip Generation

From the foregoing it is clear that the pattern of truck terminals in itself does not contribute in any meaningful way to the general distributional pattern of truck trips, except that it does appear to influence the pattern of the small segment of trips performed by heavy trucks. This is hardly surprising, since trips to and from any truck terminal by pick-up and delivery trucks constitute only a small portion of the total number of trips performed in their respective pick-up and delivery areas.

An investigation of the over-all pattern of truck trips within the metropolitan area must, therefore, consider the entire array of functions performed by the truck in serving manufacturing, wholesale and retail commercial establishments, construction and maintenance projects and the individual household.

In order to reduce the wide range of possible variables which might be related to truck trip generation to one of practical proportions, a select number of common variables must be identified.

The first of these variables is employment, which might be regarded as a measure of output, thus of transportation demand, in both the manufacturing and service industries. This variable may be conveniently expressed in terms of first work trips. The second is population, considered as a trip-generating variable in terms of goods delivery, public utility construction and services. A third possible variable, relating to retail sales, might be added by way of refinement.

The relative spatial distribution of first work trips, population and truck trips as shown in Figure 13 suggests that a reasonable relationship exists between the dependent and two independent variables. Undoubtedly this relationship could be improved upon by categorizing first work trips by type of employment or population by income groups, or by adding the retail sales variable. As a basic relationship, however, expressing the number of truck trips generated in terms of certain variables whose patterns of spatial distribution are subject to continual change within the metropolis, it is entirely adequate as can be shown by multi-correlation techniques.

By correlating the values of the three variables over 44 "Districts" as defined in the Chicago Area Transportation Study, the following relationship evolves (2):

$$T = -9.411 + 0.1777\,E + 0.1063\,P$$

where T = Total number of Truck Trips
E = First Work Trips (Employment)
P = Population

With a multiple-correlation coefficient of $R_{T:EP} = 0.9053$ and coefficients of partial correlation $r_{TE \cdot P} = 0.8180$ and $r_{TP \cdot E} = 0.7094$, this simple relationship illustrates reasonably well how the pattern of truck trips might be expected to change with changes in the patterns of employment and population within the metropolitan area.

The Changing Pattern of Truck Trips

In terms of growth, changes in truck registrations have been less spectacular than those in automobile registrations.

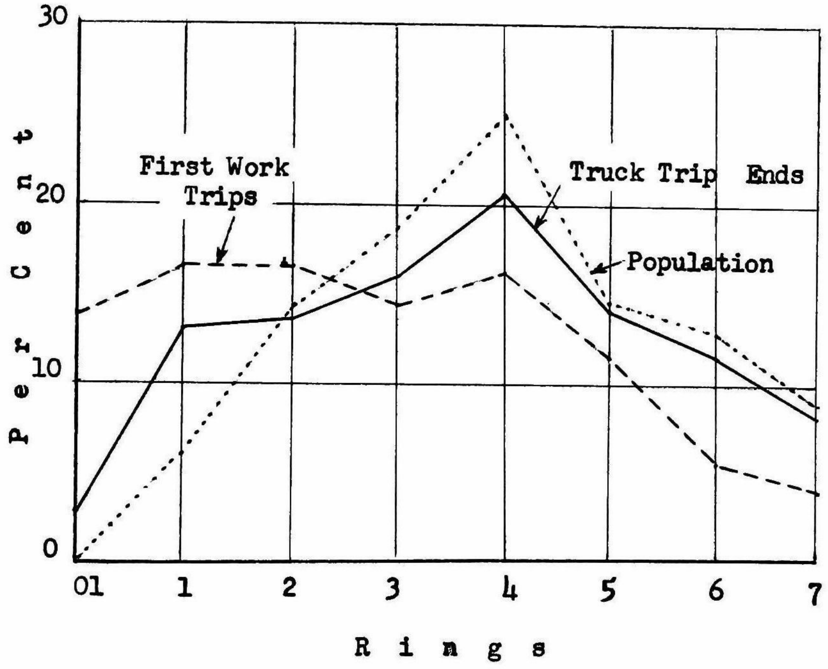


FIGURE 13

RELATIVE DISTRIBUTION OF TRUCK TRIP ENDS, POPULATION AND FIRST WORK TRIPS (EMPLOYMENT)

Metropolitan Area of Chicago, 1956

Source: See Tables (xi), (xxi), and (xxii) in the Appendix.

- During the past decade automobile registration in Cook County increased by 65%, as compared to an increase of only 11.8% in truck registrations (3).

Growth in itself does not explain changes in truck trip patterns within the metropolitan area. The effects of employment and population on trip generation and of regulation on truck trip concentration on certain routes have already been mentioned. Apart from these effects, technological innovations in the truck, the roadway and in handling equipment have all contributed actively to changes in the truck trip pattern.

Mechanical and structural improvements to the line-haul vehicle have been directly responsible for the substantial increase in intercity ton-miles produced by the trucking industry, thus generating interline freight which in turn draws the activity of large trucks toward circumferential arterials, away from the city center.

- Apart from devices such as airbrakes or refrigeration, one of the major features in innovation has been an increase in the capacity of the trailer coupled with a decrease in its weight. Where previously a 35 ft. trailer weighed 18,000 lbs., a 40 ft. trailer (with 2,700 cu. ft. capacity as against 2,250 cu. ft. of the 35 ft. trailer) now weighs only 7,650 lbs. (4)
- As regards growth in freight movement: inter-city truck ton-miles (for the United States) increased from 172,860 million in 1950 to an estimated 260,000 million in 1958, an increase of 50% (5).

As for the smaller trucks, it is not so much the increase in mechanical reliability and versatility which has contributed to changes in their operational pattern but, rather, innovations in communication and containerization. The possibilities of radio communication, containerization in its many forms and consolidation of freight are still far from being fully explored. There is little doubt that the coming decade will see a greater acceptance of these means.

Perhaps more pronounced than technological innovations to operational methods have been technological improvements to the roadway system in changing the pattern of truck trips. The extensive system of free flowing arterials presently under construction within the metropolitan area of Chicago can ultimately be expected to have a very definite effect upon the over-all truck traffic pattern.

> • Most sections of the expressway system have been opened too recently to determine empirically changes in the pattern of truck trips. With a saving of 9.93¢ per vehicle mile for heavy trucks and of 4.66¢ per vehicle mile for pick-up and delivery trucks (6), a change toward increased expressway use by truck operators is entirely conceivable. Of course, the possibility should not be overlooked that truck operators may regard the expressways as being too crowded with automobiles and for this reason prefer to revert back to the now less-congested city streets.

An indication of the outward movement of truck trip ends from the area of concentrated activity is best found by considering only that section of the metropolitan area which falls within the city limits of Chicago.

The relative number of truck trip ends, as related to distance from the Loop, are shown in Figure 14 for the years 1950 (7) and 1956 (1). (See Tables xvii and xviii in the appendix for a more detailed presentation of these data.)

The increase in truck registrations in Cook County of 8.8 per cent during the period 1950-1956 leads to the fair assumption that the outward movement of truck trips has not only been relative, but absolute as well. It will be further noticed from Figure 14 that the outward movement of truck trip ends originated in the area contained within

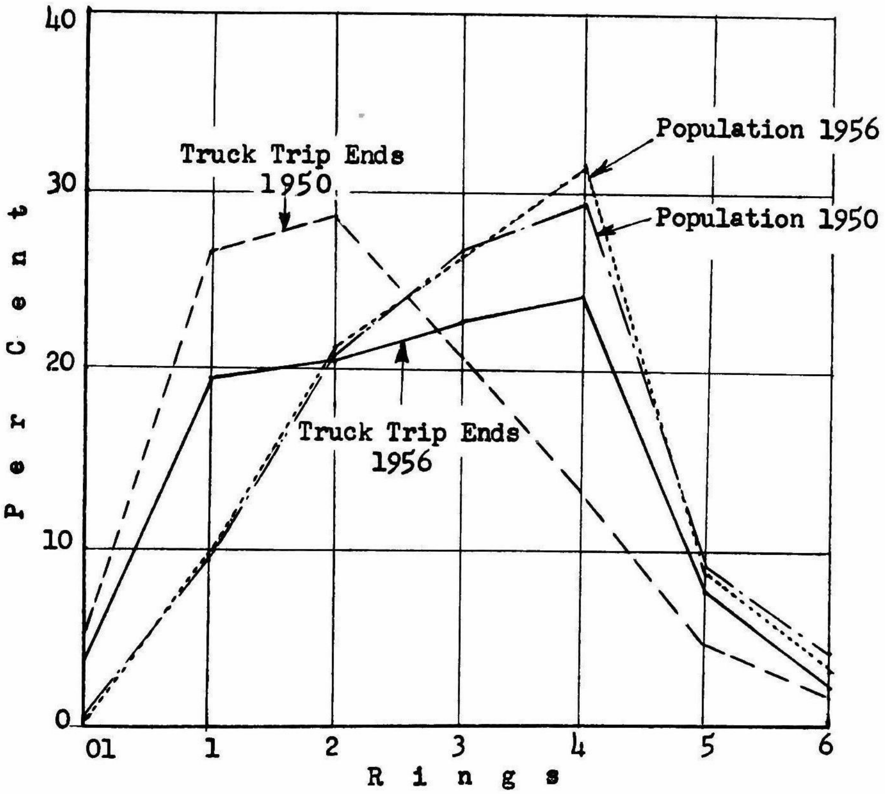


FIGURE 14

RELATIVE DISTRIBUTION OF TRUCK TRIP ENDS AND POPULATION
1950 AND 1956

City of Chicago

Source: See Tables (xvii), (xviii), (xix) and (xx) in the Appendix.

a 4.5 mile radius from a central point in the Loop.

Corresponding changes in the pattern of relative population distribution (8, 1) are less pronounced, though a slight relative increase does appear to be indicated in Figure 14. (See Tables xix and xx in the appendix for a more detailed presentation of these data.) This suggests that the population variable in itself is not sufficient to explain shifts in the distributional pattern of truck trip ends, but that one or more variables are required to produce a more reliable trend, particularly when only a specific section of the metropolitan area is considered.

Although the number of truck trips has decreased in the area within a 4.5 mile radius from the Loop during the period 1950-1956, the number of service vehicles entering and leaving the Loop has remained remarkably constant, suggesting at the most a slight decrease as well.

TABLE 7

DAILY NUMBER OF VEHICLES ENTERING AND LEAVING THE CENTRAL BUSINESS DISTRICT

City of Chicago

Year	Service Vehicles	All Vehicles
1950	41,722	381,077
1952	42,129	382,847
1954	42,978	411,404
1956	40,745	429,787
1958	39,915	463,187

Source: Cordon Count Data, Bureau of Street Traffic, City of Chicago, 1958.

From Table 7 it is obvious that the proportion of trucks entering the central business district has been decreasing relative to all vehicle trips, a phenomenon which might be ascribed to improved handling methods of freight due to consolidation and radio control and to the outward movement of certain economic activities.

An Appraisal of the Theoretical and Analytical Approaches in Terms of Actual Findings

The empirical evaluation of available data on truck trips was found to verify what the theoretical and analytical approaches had already suggested: a general outward movement of truck trip ends.

Both the analytical and empirical investigations emphasized the dire need for additional study in the field of truck transportation within the metropolitan area.

Of the six traffic-generating models mentioned in the analytical approach, none considered truck traffic generation to be of much consequence. As was suggested, some of these models might well be adapted for determining the number of truck trips generated between different areas of the metropolis.

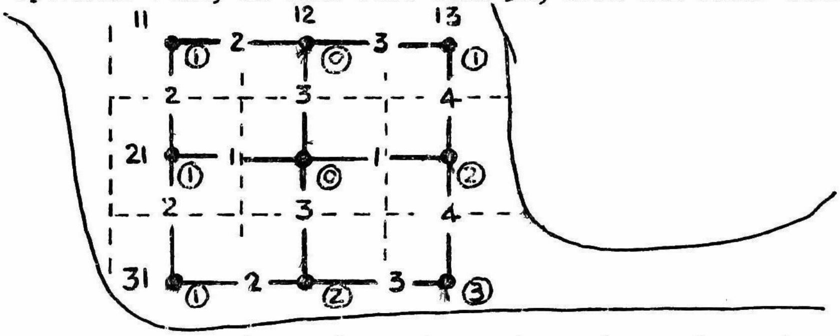
The attempts at correlating truck trip ends to such factors as employment, population and retail sales, on the other hand, are both commendable and encouraging. They constitute the first hopeful signs of quantifying the outward movement of truck trips in terms of variables with known or expected values. It is in this field that further efforts promise to be most rewarding.

APPENDIX

EXAMPLE I

Example of the Uncapacitated Transportation Network Problem.

The diagram below shows a metropolitan area divided into nine cells, each of which has a given freight demand. The cost of transportation per unit of freight between adjoining cells is also given.
The problem is to find the minimum cost of transportation to a specific cell, in this case cell 31, from all other cells.



x_{ij}			11	13	21	23	32	33	12	22	31
	1	11			2^1				2		
	1	13				4^1			3		
IN	1	21	2							1	2^5
	2	23		4				4		1^3	
	2	32						3		3	2^5
	3	33				4	3^3				
TRANS-		12	2	3						2	
SHIPMENT		22			1^3	1	3		3		
OUT		31			2		2				

The above matrix is the initial cost matrix for the sample network with terminal node at 31. Indicated in this matrix are also the amounts to be shipped from and through each node. The iterative procedure required to determine these quantities is not shown.

The minimum cost of shipping all x_{ij}'s to node 31 is:

$$2x1 + 4x1 + 2x5 + 1x3 + 2x5 + 3x3 + 1x3 = 41$$

In this way, by rearranging the rows and columns (not necessarily of the original cost matrix, but preferably of a subsequent matrix in the process of iteration) the minimum cost of shipping from all ij's to all other nodes can be determined.

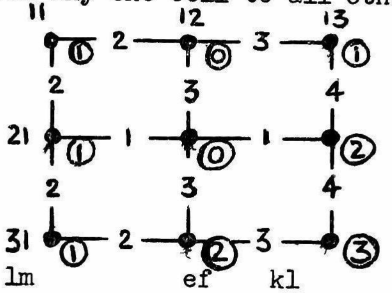
This method of evaluation is equally applicable where a cell such as 31 is regarded as the output node and all corresponding output nodes as input nodes. Furthermore, there are no constraints on the regularity of the network.

Evaluation of the line-haul costs or transhipment costs at any cell, are simply variations of the foregoing procedure. Obviously, both the inputs and the unit transportation costs would need to be adjusted in each new case where different volumes of freight are handled and different vehicles used.

EXAMPLE II

Example to Illustrate Sensitivity of Pick-up and Delivery Cost Variable.

In this example the same network and quantities have been taken, as in the previous example. The cost matrix shows the cost per unit of freight from any one cell to all other cells.



	x_{ij}		11	12	lm 13	21	ef 22	kl 23	31	32	33
	1	11	0	2	5	2	3	4	4	6	9
	0	12	2	0	3	4	3	4	6	6	8
lm	1	13	5	3	0	6	5	4	9	9	8
	1	21	2	4	6	0	1	2	2	4	6
ef	0	22	3	3	5	1	0	1	3	3	5
kl	2	23	4	4	4	2	1	0	4	4	4
	1	31	4	6	9	2	3	4	0	2	5
	2	32	6	6	9	4	3	4	2	0	3
	3	33	9	8	8	6	5	4	5	3	0
$_{pd}K_{ij}$			58	59	70	40	35	34	42	38	42
Δc^{ef}_{kl}								1			
ΔK^{ef}_{kl}							1 -	1			
Δx_{ef}							1				
ΔK^{ij}_{lm}			12	11	0	30	35	36	28	32	28
Δc^{lm}_{ij}			5	3	0	6	5	4	9	9	8
Δx_{lm}			2.4	3.7	0	5.0	7.0	9.0	3.1	3.4	3.5

In order to move the terminal from cell 23 to cell 22, the cell of second least cost, more than one unit of freight must be added to cell 22. The same effect is produced by adding more than one unit of freight to either of the cells 11, 12, 22, 31, or 32.

Only if the additional amount of freight is greater than 8.3 units will the terminal move from cell 23 to cell 13. For that same amount of additional freight, it would also move to any of the other cells.

TABLE i

COMMON CARRIERS - GENERAL FREIGHT TERMINAL ADDRESSES

1960

Metropolitan Area of Chicago

		SECTORS									
		1	2	3	4	5	6	7	8	Total	%
RINGS	1	122	-	-	-	-	-	-	-	122	22.4
	2	0	7	9	16	92	47	19	-	190	34.9
	3	2	3	3	27	24	9	1	-	69	11.0
	4	3	2	1	1	47	4	2	-	60	12.7
	5	0	1	6	0	11	2	5	-	25	4.6
	6	0	1	5	1	0	6	10	1	24	4.4
	7	0	0	0	0	1	5	2	19	27	5.0
	8	2	0	6	12	2	0	0	0	22	4.0
	9	0	2	1	0	1	0	1	0	5	1.0
Total		122 7	16	31	57	178	73	40	20	544	100.0
%*		1.6	3.8	7.4	13.5	42.2	17.3	9.5	4.7	100.0	-

*Excluding Ring 1, Sector 1.

Source: "Leonard's Guide" Motor Freight Directory for Chicago, 1960.

TABLE ii

COMMON CARRIERS - GENERAL FREIGHT TERMINAL ADDRESSES

1950

Metropolitan Area of Chicago

		SECTORS									
		1	2	3	4	5	6	7	8	Total	%
	1	185	-	-	-	-	-	-	-	185	35.9
	2	0	4	14	15	92	53	34	-	212	41.1
	3	0	3	5	7	13	13	3	-	44	8.6
R	4	0	1	4	0	16	0	3	-	24	4.7
I	5	0	0	3	0	0	1	8	-	12	2.3
N	6	0	2	1	0	0	4	2	1	10	1.9
G	7	0	0	0	0	0	3	1	3	7	1.4
S	8	2	1	2	11	2	0	0	0	18	3.5
	9	0	0	0	2	1	0	0	0	3	0.6
Total		185 2	11	29	35	124	74	51	4	515	100.0
%*		0.6	3.3	8.8	10.6	37.6	22.4	15.5	1.2	100.0	-

*Excluding Ring 1, Sector 1.

Source: "Leonard's Guide" Motor Freight Directory for Chicago, 1950.

TABLE iii

COMMON CARRIERS - GENERAL FREIGHT
TERMINAL ADDRESSES: CLASS I CARRIERS

1960

Metropolitan Area of Chicago

		SECTORS									
		1	2	3	4	5	6	7	8	Total	%
	1	33	0	0	0	0	0	0	0	33	14.9
	2	0	0	3	7	44	20	8	0	82	36.9
	3	0	0	0	13	15	4	1	0	33	14.9
R	4	2	0	0	1	36	3	0	0	42	18.9
I	5	0	0	0	0	7	1	2	0	10	4.5
N	6	0	0	0	0	0	2	4	1	7	3.1
G	7	0	0	0	0	0	1	0	13	14	6.3
S	8	0	0	0	0	0	0	0	0	0	0.0
	9	0	0	0	0	0	0	1	0	1	0.5
Total		33 2	0	3	21	102	31	16	14	222	100.0
%*		1.0	0	1.6	11.1	54.0	16.4	8.5	7.4	100.0	-

*Excluding Ring 1, Sector 1.

Source: "Leonard's Guide" Motor Freight Directory for Chicago, 1960.

Trinc's Blue Book of the Trucking Industry, Trinc, Washington, D.C., 1959.

TABLE iv

COMMON CARRIERS - GENERAL FREIGHT
TERMINAL ADDRESSES: CLASS II CARRIERS

1960

Metropolitan Area of Chicago

		SECTORS									
		1	2	3	4	5	6	7	8	Total	%
	1	26	-	-	-	-	-	-	-	26	23.6
	2	-	2	2	5	22	12	2	-	45	40.9
	3	-	0	0	5	6	1	0	-	12	10.9
R	4	-	0	0	0	5	1	2	-	8	7.3
I	5	-	1	0	0	0	0	2	-	3	2.7
N	6	-	0	2	0	0	0	3	0	5	4.5
G	7	-	0	0	0	0	2	1	3	6	5.5
S	8	-	0	1	1	2	0	0	0	4	3.6
	9	-	1	0	0	0	0	0	0	1	1.0
Total		26 0	4	5	11	35	16	10	3	110	100.0
%*		0	4.8	5.9	13.1	41.6	19.1	11.9	3.6	100.0	-

*Excluding Ring 1, Sector 1.

Source: "Leonard's Guide" Motor Freight Directory for Chicago, 1960.
Trinc's Blue Book of the Trucking Industry, Trinc, Washington, D.C., 1959.

TABLE v

COMMON CARRIERS - GENERAL FREIGHT
TERMINAL ADDRESSES: CLASS III CARRIERS

1960

Metropolitan Area of Chicago

		SECTORS									
		1	2	3	4	5	6	7	8	Total	%
	1	63	-	-	-	-	-	-	-	63	29.8
	2	0	5	4	4	26	15	9	-	63	29.8
	3	2	3	3	9	3	4	0	-	24	11.2
R	4	1	2	1	0	6	0	0	-	10	4.7
I	5	0	0	6	0	4	1	1	-	12	5.7
N	6	0	1	3	1	0	4	3	0	12	5.7
G	7	0	0	0	0	1	2	1	3	7	3.2
S	8	2	0	5	11	0	0	0	0	18	8.5
	9	0	1	1	0	1	0	0	0	3	1.4
Total		68 5	12	23	25	41	26	14	3	212	100.0
%*		3.4	8.0	15.4	16.8	27.5	17.5	9.4	2.0	100.0	-

*Excluding Ring 1, Sector 1.

Source: "Leonard's Guide" Motor Freight Directory for Chicago, 1960.
Trinc's Blue Book of the Trucking Industry, Trinc, Washington, D.C., 1959.

TABLE vi

COMMON CARRIERS - GENERAL FREIGHT
ADDRESSES OF CARRIERS WITH NO 1950 ADDRESSES

1960

Metropolitan Area of Chicago

	SECTORS									
RINGS	1	2	3	4	5	6	7	8	Total	%
1	39	-	-	-	-	-	-	-	39	22.4
2	0	3	2	6	22	18	4	-	55	31.6
3	1	0	2	5	1	1	0	-	10	5.7
4	1	1	1	0	16	1	1	-	21	12.1
5	0	0	5	0	5	1	2	-	13	7.5
6	0	0	3	0	0	0	7	0	10	5.7
7	0	0	0	0	1	1	1	14	17	9.8
8	1	0	1	7	0	0	0	0	9	5.2
9	0	0	0	0	0	0	0	0	0	0.0
Total	42 3	4	14	18	45	22	15	14	174	100.0
%*	2.2	3.0	10.4	33.3	33.3	16.3	11.1	10.4	100.0	-

*Excluding Ring 1, Sector 1.

Source: "Leonard's Guide" Motor Freight Directory for Chicago, 1960.

TABLE vii

COMMON CARRIERS - GENERAL FREIGHT CARRIERS WHO RETAINED 1950 ADDRESSES

1960

Metropolitan Area of Chicago

		SECTORS									
		1	2	3	4	5	6	7	8	Total	%
	1	41	-	-	-	-	-	-	-	41	29.3
	2	0	2	6	8	19	12	6	-	53	37.9
	3	0	3	0	3	5	4	1	-	16	11.4
R	4	0	1	0	0	6	0	1	-	8	5.7
I	5	0	0	1	0	0	0	3	-	4	2.8
N	6	0	1	1	0	0	2	0	1	5	3.6
G	7	0	0	0	0	0	2	1	2	5	3.6
S	8	0	0	2	4	1	0	0	0	7	5.0
	9	0	0	0	0	1	0	0	0	1	0.7
Total		41 0	7	10	15	32	20	12	3	140	100.0
%*		0	7.1	10.1	15.2	32.3	20.2	12.1	3.0	100.0	-

*Excluding Ring 1, Sector 1.

Source: "Leonard's Guide" Motor Freight Directory for Chicago, 1960.

TABLE viii

COMMON CARRIERS - GENERAL FREIGHT CARRIERS WHO CHANGED ADDRESS SINCE 1950

1960

Metropolitan Area of Chicago

		SECTORS									
		1	2	3	4	5	6	7	8	Total	%
RINGS	1	42	-	-	-	-	-	-	-	42	18.3
	2	0	2	1	2	51	17	9	-	82	35.6
	3	1	0	1	19	18	4	0	-	43	18.7
	4	2	0	0	1	25	3	0	-	31	13.5
	5	0	1	0	0	6	1	0	-	8	3.5
	6	0	0	1	1	0	4	3	0	9	3.9
	7	0	0	0	0	0	2	0	3	5	2.2
	8	1	0	3	1	1	0	0	0	6	2.6
	9	0	2	1	0	0	0	1	0	4	1.7
Total		46 4	5	7	24	101	31	13	3	230	100.0
%*		2.1	2.7	3.7	12.8	53.7	16.5	6.9	1.6	100.0	-

*Excluding Ring 1, Sector 1.

Source: "Leonard's Guide" Motor Freight Directory for Chicago, 1960.

TABLE ix

MANUFACTURING LAND (In Use)
(Acres)

1956

Metropolitan Area of Chicago

		SECTORS								
		1	2	3	4	5	6	7	Total	%
	01	9.6							9.6	0.06
	1	549.7							549.7	3.48
RINGS	2	63.8	297.3	228.1	98.6	425.6	422.2	82.8	1618.4	10.25
	3	62.4	282.4	392.7	324.9	527.3	322.0	27.0	1938.7	12.28
	4	198.6	144.6	234.8	440.4	600.3	252.9	282.3	2153.9	13.64
	5	231.1	535.7	756.8	1091.1	992.5	72.3	812.4	4491.9	28.45
	6	99.1	292.2	470.1	106.7	291.6	622.9	1637.9	3520.5	22.29
	7	129.2	205.7	219.4	190.3	34.7	288.9	440.0	1508.2	9.55
Total		559.3 784.2	1757.9	2301.9	2252.0	2875.0	1981.2	3282.4	15790.9	100.00
%*		8.51	11.13	14.57	14.26	18.20	12.55	20.78	100.0	-

*Excluding Ring 1, Sector 1, and District 01.

Source: Chicago Area Transportation Study, Vol. I, 1956.

TABLE x

COMMERCIAL LAND (In Use)
(Acres)

1956

Metropolitan Area of Chicago

		S E C T O R S								
		1	2	3	4	5	6	7	Total	%
	01	147.4							147.4	1.09
	1	913.5							913.5	6.77
R	2	240.7	270.9	277.0	181.5	286.0	160.7	176.4	1593.2	11.80
I	3	247.4	301.1	306.9	278.2	239.1	235.6	295.9	1904.2	14.10
N	4	464.6	442.6	452.5	275.2	204.1	425.9	466.2	2731.1	20.23
G	5	218.5	347.2	449.0	173.5	181.5	290.0	378.0	2037.7	15.09
S	6	216.9	473.4	485.6	317.6	232.1	390.8	287.1	2403.5	17.80
	7	191.8	350.1	287.4	273.5	55.8	451.8	160.5	1770.9	13.12
	Total	1060.9 1579.9	2185.3	2258.4	1499.5	1198.6	1954.8	1764.1	13501.5	100.00
	%*	12.70	17.57	18.15	12.05	9.64	15.71	14.18	100.0	-

*Excluding Ring 1, Sector 1, and District 01.

Source: Chicago Area Transportation Study, 1956.

TABLE xi

TOTAL TRUCK TRIP ENDS
INTERNAL AND EXTERNAL

1956

Metropolitan Area of Chicago

			SECTORS								
			1	2	3	4	5	6	7	Total	%
RINGS	01	L	6,212							6,212	2.0
		M	14,686							14,686	3.2
		H	990							990	1.5
		T	21,888							21,888	2.65
	1	L	26,820							26,820	8.8
		M	71,231							71,231	15.6
		H	10,303							10,303	15.3
		T	108,354							108,354	13.09
	2	L	5,151	8,309	6,313	3,354	4,581	2,886	3,584	34,178	11.3
		M	7,631	12,428	13,239	7,517	11,190	8,525	6,617	67,147	14.7
		H	554	1,197	835	839	3,783	2,908	1,178	11,294	16.8
		T	13,336	21,934	20,387	11,710	19,554	14,219	11,379	112,619	13.61
	3	L	7,059	7,780	7,236	6,342	5,846	4,645	7,523	46,431	15.3
		M	9,800	14,531	14,872	9,290	11,270	7,621	8,303	75,687	16.3
		H	720	1,434	1,665	2,333	2,970	890	378	10,390	15.5
		T	17,579	23,745	23,773	17,965	20,086	13,156	16,204	132,508	16.02
	4	L	10,854	11,079	12,312	10,961	4,668	12,086	12,490	74,450	24.6
		M	15,857	17,806	12,459	9,158	8,108	13,144	10,806	87,338	19.2
		H	872	1,197	1,760	1,353	2,854	1,961	1,067	11,064	16.5
		T	27,583	30,082	26,531	21,472	15,630	27,191	24,363	172,852	20.89

Continued

TABLE xi
(cont)

			SECTORS								
			1	2	3	4	5	6	7	Total	%
RINGS	5	L	8,026	7,684	9,027	3,430	2,643	6,221	8,653	45,684	15.0
		M	8,304	13,321	11,853	6,074	5,318	6,041	8,494	59,405	13.0
		H	1,367	1,127	1,783	1,918	1,777	1,664	1,247	10,883	16.1
		T	17,697	22,132	22,663	11,422	9,738	13,926	18,394	115,972	14.02
	6	L	5,964	5,583	5,279	4,192	2,380	8,188	6,765	38,351	12.6
		M	4,027	6,862	14,043	9,167	3,685	6,207	5,857	49,848	10.9
		H	332	758	1,573	919	1,536	1,492	1,745	8,355	12.4
		T	10,323	13,203	20,895	14,278	7,601	15,887	14,367	96,554	11.67
	7	L	5,243	10,011	2,734	4,107	819	6,203	2,751	31,868	10.4
		M	3,435	5,494	3,716	5,086	1,008	8,684	3,390	30,813	6.8
		H	665	600	185	331	268	799	1,113	3,961	5.9
		T	9,343	16,105	6,635	9,524	2,095	15,686	7,254	66,642	8.05
TOTAL		L	33,032								
		M	85,917								
		H	11,293								
		T	130,242								
		L	42,297	50,446	42,901	32,386	20,937	40,229	41,766	303,994	36.74
		M	49,054	70,442	70,182	46,292	40,579	50,222	43,467	456,155	55.13
		H	4,510	6,313	7,801	7,693	13,188	9,714	6,728	67,240	8.13
		T	95,861	127,201	120,884	86,371	74,704	100,165	91,961	827,389	100.00
%*			13.75	18.24	17.34	12.39	10.72	14.37	13.19	100.00	-

*Excluding Ring 1, Sector 1, and District 01.

Source: Chicago Area Transportation Study, 1956.

TABLE xii

CHANGES IN EMPLOYMENT

1955 - 1959

Metropolitan Area of Chicago

	EMPLOYMENT					
Rings	1955	%	1959	%	Change	%
01	220,689	14.19	217,280	13.34	- 3,409	- 2.51
1	344,380	22.14	337,711	20.73	- 6,669	- 4.91
2	217,206	13.96	208,714	12.82	- 8,492	- 6.26
3	244,722	15.74	232,144	14.25	-12,578	- 9.26
4	232,007	14.92	237,601	14.59	+ 5,594	+ 4.11
5	158,734	10.21	191,148	11.74	+32,414	+23.87
6	93,586	6.02	136,855	8.40	+43,269	+31.86
7	43,930	2.82	67,318	4.13	+23,388	+17.22
Total	1,555,254	100.00	1,628,771	100.00	-	-

Sectors	1955	%	1959	%	Change	%
1	111,666	11.28	126,752	11.80	+15,086	+18.04
2	145,307	14.67	175,163	16.31	+29,856	+35.72
3	189,755	19.16	216,977	20.21	+27,222	+32.58
4	138,398	13.98	143,252	13.34	+ 4,854	+ 5.80
5	145,018	14.65	145,510	13.55	+ 492	+ 0.58
6	138,122	13.95	140,522	13.09	+ 2,400	+ 2.87
7	121,919	12.31	125,604	11.70	+ 3,685	+ 4.41
Total	990,185	100.00	1,073,780	100.00	-	-

Source: AMA Study, Transportation Center, 1960

TABLE xiii

PLANT RELOCATIONS

1950 - 1959

Metropolitan Area of Chicago

IN			OUT		CHANGE		
Ring	No.	Cost (000's)	No.	Cost (000's)	No.	%	Cost (000's)
1	61	6,388	313	119,516	-252	30.00	-113,128
2	129	20,326	245	112,155	-116	-13.81	- 91,829
3	160	36,249	212	80,775	- 52	- 6.20	- 44,526
4	157	47,308	136	67,825	+ 21	2.50	- 20,514
5	299	146,703	73	21,301	+226	26.90	+125,402
6	96	87,876	19	9,506	+ 77	9.17	+ 78,370
7	75	48,259	8	1,505	+ 67	7.98	+ 46,754
8	34	36,746	6	19,635	+ 28	3.32	+ 17,111
9	4	2,025	3	565	+ 1	0.12	+ 2,360

Source: AMA Study, Transportation Center, 1960.

TABLE xiv

COMMON CARRIERS - GENERAL FREIGHT NET CHANGE IN TERMINAL ADDRESSES

1950 - 1960

Metropolitan Area of Chicago

RINGS	SECTORS									
	1	2	3	4	5	6	7	8	Total	%
1	-63								-63	-31.65
2		+3	-5	+ 1		-6	-15		-22	-11.05
3	+ 2		-2	+20	+11	-4	- 2		+25	12.56
4	+ 3	+1	-3	+ 1	+31	+4	- 1		+36	18.09
5		+1	+3		+11	+1	- 3		+13	6.54
6		-1	+4	+ 1		+2	+ 6		+14	7.04
7					+ 1	+2	+ 1	+16	+20	10.05
8		-1	+4	+ 1					+ 4	2.01
9		+2	+1	- 2			+ 1		+ 2	1.01
Total	-58	+5	+2	+22	+54	-1	-11	+16	+29	-

Source: "Leonard's Guide" Motor Freight Directory for Chicago, 1950 to 1960.

TABLE xv

COST OF WAREHOUSE EXPANSION
(1000 Dollars)

1950 - 1960

Metropolitan Area of Chicago

		SECTORS								
		1	2	3	4	5	6	7	Total	%
	01	44							44	0.02
	1	9,799							9,799	4.38
R	2	30	4,960	498	605	2,615	4,980	105	13,793	6.17
I	3	247	2,107	11,509	2,825	16,505	2,251	515	35,959	16.08
N	4	1,109	3,653	5,410	1,355	19,289	12,700	655	44,171	19.76
G	5	6,198	8,932	28,497	10,930	10,708	1,892	13,420	80,577	36.05
S	6	350	7,850	18,642	0	120	6,900	3,176	37,038	16.57
	7	300	350	0	250	150	830	294	2,174	0.97
Total		9,843 8,234	27,852	64,556	15,965	49,387	29,553	18,165	223,555	100.00
%		4.40 3.68	12.46	28.88	7.14	22.09	13.22	8.13	100.00	-

Source: Distributional Pattern of Warehouses, AMA Study, 1960.

TABLE xvi

ALL VEHICLE TRIP DESTINATIONS

1956

Metropolitan Area of Chicago

	SECTORS								
RINGS	1	2	3	4	5	6	7	Total	%
01	144,197							144,197	2.42
11	414,878							414,878	6.98
2	105,161	94,659	110,334	64,629	65,316	53,778	65,892	559,769	9.42
3	128,812	153,281	158,577	94,880	83,893	75,833	117,149	812,425	13.67
4	196,009	188,982	247,928	152,521	96,217	207,812	241,359	1,330,828	22.38
5	160,470	183,171	156,598	103,751	91,818	157,842	168,166	1,021,816	17.19
6	123,266	139,983	160,538	138,630	63,400	197,473	142,505	965,795	16.25
7	101,527	117,883	86,116	88,723	18,309	207,129	75,055	694,742	11.69
Total	559,075 815,245	877,959	920,091	643,134	418,953	899,867	810,126	5,944,450	100.00
%	9.40 13.71	14.77	15.48	10.82	7.05	15.14	13.63	100.00	-

Source: Chicago Area Transportation Study, Vol. I., 1956.

TABLE xvii

TOTAL NUMBER OF TRUCK STOPS PERFORMED DAILY BY MOTOR CARRIERS

1950

City of Chicago

	SECTORS								
RINGS	1	2	3	4	5	6	7	Total	%
01	6,718							6,718	5.23
1	34,018							34,018	26.49
2	2,775	4,160	5,528	3,777	8,332	6,187	5,975	36,734	28.62
3	2,119	3,894	4,799	2,721	6,666	3,700	2,416	26,315	20.49
4	1,697	3,282	2,967	242	4,154	2,324	2,324	16,990	13.23
5		1,335	308		1,346	1,033	1,724	5,746	4.48
6						682	1,197	1,879	1.46
Total	40,736 6,591	12,671	13,602	6,740	20,498	13,926	13,636	128,400	100.00
%	31.73 5.13	9.87	10.59	5.25	15.96	10.85	10.62	100.00	-

Note: Zones of "Committee on Motor Truck Terminuses" converted to CATS Districts. Number of truck stops assumed in direct relationship to zone area.

Source: "Report and Recommendations," Committee on Motor Truck Terminuses, City of Chicago, 1950, Chicago Area Transportation Study-Zones.

TABLE xviii

NUMBER OF INTERNAL TRUCK TRIP ENDS WITHIN MUNICIPAL BOUNDARY OF CHICAGO

1956

City of Chicago

		SECTORS								
		1	2	3	4	5	6	7	Total	%
	01	21,684							21,684	4.01
RINGS	1	105,566							105,566	19.50
	2	13,211	21,643	20,116	11,392	17,913	13,243	11,119	108,637	20.07
	3	17,463	23,566	23,418	11,176	19,430	12,818	16,045	123,916	22.89
	4	25,380	28,209	14,942	1,062	10,130	26,843	24,021	130,587	24.13
	5		10,968	1,445		1,680	8,259	17,725	40,077	7.40
	6						2,930	7,919	10,849	2.00
Total		127,250 56,054	84,386	59,921	23,630	49,153	64,093	76,829	541,316	100.00
%		23.51 10.36	15.59	11.07	4.37	9.08	11.84	14.18	100.00	-

Note: Number of trips assumed in direct relationship to proportion of CATS Districts within municipal boundary.

Source: Chicago Area Transportation Study, 1956.

TABLE xix

POPULATION

1950

City of Chicago

	SECTORS								
RINGS	1	2	3	4	5	6	7	Total	%
01	18,900							18,900	0.52
1	328,500							328,500	9.12
2	137,600	116,500	162,800	76,000	73,000	49,600	137,400	752,900	20.92
3	166,900	162,500	154,400	67,900	94,100	103,200	214,600	963,600	26.77
4	192,700	170,300	134,900	10,400	75,400	172,000	299,800	1,055,500	29.32
5		76,500	17,500		32,800	86,400	111,500	324,700	9.02
6						47,900	108,000	155,900	4.33
7									
Total	347,400 497,200	525,800	469,600	154,300	275,300	459,100	871,300	3,600,000	100.00
%	9.64 13.82	14.62	13.04	4.27	7.65	12.76	24.20	100.00	-

Source: Preliminary 1950 Population of the City of Chicago. Chicago Plan Commission, CATS District Map.

TABLE xx

POPULATION

1956

City of Chicago

	SECTORS								
RINGS	1	2	3	4	5	6	7	Total	%
01	4,954							4,954	0.14
1	317,557							317,557	9.15
2	137,010	115,974	161,881	99,488	59,744	43,298	128,217	745,612	21.48
3	160,772	159,425	145,172	70,666	70,781	100,072	216,070	922,958	26.60
4	175,737	168,673	118,550	61,252	59,221	214,550	290,070	1,088,053	31.36
5		66,029	7,448		1,292	74,313	141,674	290,756	8.38
6						28,152	71,714	99,866	2.89
Total	322,511 473,519	510,101	433,051	231,406	191,038	460,385	847,745	3,469,756	100.00
%	9.29 13.65	14.70	12.47	6.67	5.51	13.66	24.42	100.00	-

Source: Chicago Area Transportation Study, Vol. I, 1956.

TABLE xxi

FIRST WORK TRIPS - ALL MODES

1956

Metropolitan Area of Chicago

		SECTORS								
		1	2	3	4	5	6	7	Total	%
	01	254,435							254,435	14.08
	1	305,258							305,258	16.89
RINGS	2	40,392	42,132	41,959	31,978	38,730	36,083	27,014	258,288	16.53
	3	31,052	46,617	65,097	52,785	40,765	25,690	36,746	298,752	14.30
	4	40,717	44,436	45,713	40,201	28,018	42,937	51,356	293,378	16.24
	5	31,412	29,590	35,986	21,022	32,347	17,851	38,882	207,090	11.46
	6	17,649	17,068	19,943	10,017	470	26,758	26,384	118,289	6.55
	7	9,681	9,648	6,855	7,453	2,883	25,323	9,483	71,326	3.95
Total		730,596	189,491	215,553	163,456	143,213	174,642	189,865	1,806,816	100.00
%		30.97 9.46	10.48	11.93	9.05	7.93	9.67	10.51	100.00	-

Total:		
	Auto Driver:	771,006
	Auto, Truck, or Taxi Passenger:	201,467
	Railroad:	102,434
	L or Subway:	170,467
	Bus or Streetcar:	395,805
	Walk to work:	146,111
	Work at home:	19,526
		1,806,816

Source: Chicago Area Transportation Study, 1956,
From Table # 42-2.

TABLE xxii

POPULATION

1956

Metropolitan Area of Chicago

		SECTORS								
		1	2	3	4	5	6	7	Total	%
	01	4,954							4,954	0.10
RINGS	1	317,557							317,557	6.14
	2	137,010	115,974	161,881	99,488	59,744	43,298	128,217	745,612	14.42
	3	160,772	159,425	145,172	110,415	70,781	100,072	216,070	962,707	18.62
	4	189,986	178,490	207,982	122,504	82,827	214,550	290,070	1,286,409	24.88
	5	100,176	132,057	114,588	70,418	71,752	123,856	141,674	754,521	14.60
	6	65,564	92,474	117,647	79,283	46,587	145,867	107,036	654,458	12.66
	7	57,013	79,623	58,858	59,097	11,948	121,220	55,686	443,445	8.58
Total		322,511 710,521	758,043	806,128	541,205	343,639	748,863	938,753	5,169,663	100.00
%		6.24 13.74	14.66	15.59	10.47	6.65	14.49	18.16	100.00	-

Source: Chicago Area Transportation Study, Vol. I., 1956.

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