THE TRANSPORT OF GOODS
AND URBAN SPATIAL STRUCTURE

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THE TRANSPORT OF GOODS AND URBAN SPATIAL STRUCTURE

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Apart from this assistance, I declare for the purposes of University Ordinances that this dissertation is my original work and includes nothing which is the outcome of work done in collaboration.

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Chapter 1 Introduction and Summary

Background

During the past few years there has been growing recognition that a wide variety of planning problems are associated with the transport of freight within urban areas (Sharp, 1973; Hicks, 1977). Some of these planning problems involve the amelioration of externalities such as noise, pollution, and congestion. Others include the siting of freight terminals, the improvement of economic efficiency in physical distribution, and, more generally, the treatment of goods vehicle traffic within the context of comprehensive urban transport planning.

The practice of urban transport planning requires an understanding of the determinants of existing traffic patterns and the likely impacts of policies and investments on the demand for passenger and freight transport. This knowledge is essential in planning for goods transport facilities and improving freight transport operations in urban areas. Since both passenger and commercial vehicles share the use of metropolitan transport networks, assessments of the determinants of goods vehicle traffic are also necessary for the formulation and evaluation of plans for other modes of urban transport.

Traffic and transport planning problems notwithstanding, a principal motivation for planning for urban freight transport should stem from its vital role in the economic life of cities and regions. Goods transport is an obvious and essential concomitant of the spatial separation of production and consumption. In forging the economic linkages between goods producers and goods consumers within and between regions, urban freight transport intimately affects the performance and structure of economic activity within metropolitan areas (Vernon, 1957). For this reason, the benefits of facilitating the transport of goods may be more far-reaching and consequential than commonly acknowledged.

Despite the emphasis given to the concept of comprehensive land use and transport planning, there has been widespread neglect of the transport of goods within urban areas (Hedges, 1971b; Watson, 1975). Consequently, there are a large number of research questions which must be addressed in order to provide a base of knowledge which can support urban freight transport planning.

Perhaps the principal research topic in terms of its relevance to this overall objective is the nature of the short-run relationship between the activity system, the transport system, and the flows of goods vehicles. An understanding of how the generation and distribution of goods vehicle trips are related to the location, intensity, and mix of socio-economic activities, the characteristics of the transport system, and the behavior of transport providers is essential in order to assess the consequences of transport policies upon urban freight transport and to devise and evaluate improvement strategies. Because of their interdependence, investigation of the relationship between the intrametropolitan transport of goods and urban spatial structure may also provide insights on the spatial organization of activities within metropolitan areas.

Changes in the transport of goods may also lead to changes in the activity system, and understanding these effects is obviously another important research endeavor. However, freight transport is only one of many factors influencing the spatial structure of metropolitan areas; moreover, changes in urban spatial structure take place at a slow pace relative to changes in goods vehicle traffic (Chinitz, 1960; Moses and Williamson, 1967). Consequently, there is some basis for giving priority in transport research to the short-run relationship linking the transport of goods to urban spatial structure.

Research Issues and Objectives

Although a small but growing body of study has been devoted to analyzing the determinants of goods traffic, a great many theoretical and empirical issues remain unconsidered or unresolved. Of these, three issues in particular motivated and shaped the course of the research reported in this study.

The first issue concerns the scope, nature, and consequences of urban freight transport and related decisionmaking. Decisions made by a variety of entities including goods producers, goods consumers, and transport providers appear to be central determinants of spatial patterns of goods vehicle traffic within urban areas. Although studies of freight flows and industrial linkage have examined factors influencing the choice of suppliers for goods purchases, there has been virtually total neglect of the decisions made by the providers of urban freight transport. Yet, the goods vehicle trips supplied in response to the demand for goods are directly determined by decisions made by transport providers on the supply and the routing and scheduling of goods vehicles. Consequently, their decisions must be investigated to identify the range of behavioral responses to the implementation of transport policies or changes in the spatial structure of metropolitan areas.

The second issue concerns the import of the multi-destination, multi-tour goods vehicle trip patterns which appear to be characteristic of freight transport in urban areas. Although it is generally acknowledged that many goods deliveries are accomplished on trips which are linked in multi-destination tours (Wilbur Smith and Associates, 1969; Wood, 1970a; U.S. Federal Highway Administration, 1973), analyses of the determinants of goods vehicle traffic have ignored this phenomenon of "trip chaining". Trip chaining would seem to be a fundamental determinant of goods vehicle trip distribution and its relationship to the spatial arrangement of activities. A principal effect of the linkage of trips in multi-destination tours is the reduction of the cost and time required for the transport of goods (Eilon *et al.*, 1971). As a result, trip chaining may also be a significant determinant of consignment frequency and trip generation.

The presence of multi-tour, multi-destination-tour vehicle trip patterns greatly complicates the problem of determining the relationship between patterns of intraurban trade and goods vehicle trips. Trip chaining also poses a difficult conceptual problem because it suggests that decisions about individual trips are not independent of decisions about other trips made by the vehicles under the control of the same transport provider. This violates a basic assumption of the models used to quantify the relationship between the transport of goods and urban spatial structure, i.e., that goods vehicle trips are independent of one another. Consequently, the failure to take account of trip chaining may invalidate or bias theoretical and empirical analyses of the determinants of urban goods vehicle traffic.

The third issue concerns the structure and specification of a theoretically defensible framework for the analysis of the relationship between goods vehicle traffic and the activity and transport systems. Empirical analyses of urban freight transport flows have relied upon simplistic analogies with the theories of urban passenger travel or have applied existing, off-the-shelf model structures to urban freight data without adequate theoretical justification (Starkie, 1974). Consequently, a general theory of urban freight transport demand was thought to be essential for structuring a framework for empirical analysis and specifying its constituent relationships.

Many factors which have not been included in empirical studies or in proposed modelling frameworks appear to be important determinants of urban goods vehicle traffic (Ogden, 1977b; Hicks, 1977). These omitted factors include the supply of goods vehicles, temporal and physical constraints such as labor work rules, delivery deadlines and vehicle capacity, in addition to urban transport decisionmaking and trip chaining as noted previously. Incorporating these factors in the specifications of statistical models of goods vehicle traffic is necessary in order to perform valid empirical assessments of the significance and magnitude of these and its other hypothesized determinants.

Motivated by these concerns, this study entailed a program of research devoted to the investigation of the short-run relationship between the transport of goods and urban spatial structure. The overall goal of this research was to further the theoretical and empirical understanding of the determinants of goods vehicle traffic in urban areas.

As suggested by the research issues described above, the specific objectives of this study were fourfold. The first was to develop a general theory of urban freight transport behavior to be used in formulating hypotheses concerning the determinants of goods vehicle traffic. The second objective was to account for the presence and characteristics of complex multi-tour, multi-destination-tour vehicle trip patterns and to analyze their implications on the important constituent relationships linking the activity system and goods vehicle traffic. The final objectives were to develop a theoretically defensible structure for the quantitative analysis of goods vehicle traffic and to assess the significance and magnitude of a broader set of determinants of goods vehicle traffic than considered in prior research.

Although the approach taken in the empirical analysis relies on the use of statistical models to assess the determinants of goods vehicle traffic, it was not an objective of this research to develop models suitable for planning or forecasting purposes. Rather the empirical analysis is exploratory rather than comprehensive in nature, and these models are used primarily for hypothesis testing.

An Overview of the Study and its Principal Findings

Many issues concerning the determinants of urban goods vehicle traffic appear to be traceable to the absence of an adequate theoretical framework for examining these questions. This study attempts to respond to this need by proposing a theory of urban freight transport based on the decisions firms make which influence the demand for goods transport. Since the demand for urban freight transport is derived from the demand for goods exchanged within and between urban areas, decisions on the location of activities, and the production and consumption of goods are significant determinants of goods vehicle traffic. Firms also make a variety of decisions on distribution strategies including the provision of proprietary transport and vehicle supply, and these factors are also major determinants of the shipment of consignments and patterns of goods vehicle trips. Because of their longer-term nature, many of these decisions can be considered fixed for a short-run analysis of the determinants of goods vehicle traffic.

Available evidence suggests that most urban freight transport is produced by private rather than for-hire providers and that the delivery of firms' output is the primary purpose of the trips produced (Wood, 1970b). Under these "logistical arrangements," which are assumed for the theoretical analysis, the providers' transport pattern decisions, which include choices about consignments to be shipped and the trips made for this purpose, are separable from and conditional upon decisions made by purchasers of their products.

Rather detailed consideration of firms' transport pattern choices with a utility-maximizing framework suggests that the characteristics of customer demands, logistical arrangements, vehicle supply, delivery costs, transport level of service, and constraints on transport operations are among their principal determinants. A high degree of trip chaining is hypothesized to be characteristic of the outcomes of transport pattern choices because it increases the number of consignments that can be transported, reduces the costs, and may improve the level of service provided to customers with the fixed resources available to the transport provider.

Because of their multi-dimensional character, the combinatorially explosive number of alternatives, and the complex decision process employed, the analysis of the outcomes of transport pattern choices appears to be intractable without some simplifying assumptions. Useful assumptions, for which there may be some behavioral justification, are that the consignments to be transported are determined first and that the sole objective in routing vehicles is minimizing the distance/travel time required. Under these assumptions, the transport pattern choice problem reduces to the vehicle routing and scheduling problem which has been considered extensively in the operations research literature (Eilon et al., 1971).

A paradigm of the firm's trip chaining behavior is proposed which utilizes known and hypothesized characteristics of optimal and near-optimal solutions to vehicle routing problems to form hypotheses relating the characteristics of complex goods vehicle trip patterns to their determinants. The paradigm illustrates that there is a very well-defined relationship between transport provider trip generation and consignment frequency. Specifically, trip generation is shown to be an aggregate of two quantities - the consignment frequency and the tour frequency. It is also hypothesized that the average maximum number of trips or deliveries per tour (i.e., measures of trip and delivery chaining, respectively) are among the determinants of each of these components of goods vehicle trip generation.

A theoretical analysis of the cost of urban freight deliveries is presented which is based on a formula for expected distances in vehicle routing problems developed by Eilon et al. (1971). All other factors held constant, the average variable cost of a delivery in a complex transport pattern is found to decrease as a function of the number of consignments transported and the degree of trip chaining and to increase as function of the shipment length and the size of the firm's market area.

Trip chaining has a large effect on the spatial arrangement of goods vehicle trips within transport patterns. Consideration of heuristics utilized to obtain good solutions to vehicle routing problems suggests a richer set of determinants of disaggregate trip destination choice probabilities than that embodied in the usual gravity models. A further implication of the analysis is that aggregate gravity models of goods vehicle trip distribution are misspecified because they do not take account of logical restrictions on alternative trip origin-destination linkages. For example, only destinations (including the depot) which are or may be served on tours with the same origin are feasible alternatives for trip linkages.

Despite serious data limitations, an analytical approach is formulated to test the hypotheses suggested by the theory of urban freight transport behavior and to perform an empirical assessment of the determinants of urban goods vehicle traffic. The approach consists of separate multivariate statistical models of goods vehicle trip generation and trip distribution.

Based on the paradigm of trip chaining behavior, a multi-equation model is proposed for the analysis of goods vehicle trip generation which can be estimated with aggregate zonal data on industry truck trips. The model system is designed to explain the frequency of consignments and pick up and delivery trips provided by an industry from each traffic zone, the number of tours generated, the number of goods vehicle trips attracted to non-depot locations, and the total number of industry trips generated in each zone. The use of a multi-equation model, which takes account of the structural relationships which underlie industry trip generation, is thought to reduce specification error and aggregation bias present in conventional models.

The approach taken in the analysis of goods vehicle trip distribution utilizes the multinomial logit model in performing multivariate tests of hypotheses concerning the determinants of individual trip origin-destination linkages. The simplifying assumptions that the shipment pattern and the tour frequency are determined exogeneously and that the trip destination choices for each origin are independent are needed to make the modelling approach tractable. Because of conceptual problems with aggregate analysis, the methodology is a form of disaggregate analysis which is applied to data on individual goods vehicle trip patterns. Although these data differ from data on firms' trip destination choices, this procedure can be regarded as a form of sampling of alternatives and choices for multi-vehicle fleets which does not invalidate the results obtained.

The empirical analysis conducted with these models is based on data from the Boston, Massachusetts metropolitan region. The data analyzed consist of a survey of the trips made by a 10% sample of goods vehicles registered within the region and measures of the transport and activity system collected during 1963-64 as part of the Eastern Massachusetts Regional Planning Project, a comprehensive transport and land-use planning study.

A descriptive, statistical analysis of the data indicates support for some of the theoretical and empirical premises underlying the modelling approach. The importance of privately-provided urban freight transport is illustrated with evidence that substantially more than 80% of the goods vehicles operated and the trips made are by activities whose primary business is not the provision of goods transport. Perhaps the most important finding from the descriptive tabulations was evidence of an high degree of trip chaining for trips provided by many activities. The average degree of trip chaining is in excess of 9 trips per vehicle tour for vehicles operated by manufacturing, local for-hire transport, and wholesale/retail trade which together account for more than 75% of all goods vehicle trips made in the region. Quite considerable variation in rates of vehicle supply, consignment and tour frequencies, and trip generation per employee are in evidence for different activities. This finding is in accord with similar findings obtained in other studies (Starkie, 1967; Maltby, 1973) and suggests the importance of building separate models of goods vehicle trips for different industries.

The trip generation model system equations are estimated for three industrial sectors - manufacturing, local for-hire transport, and wholesale/retail trade - and also for the aggregate of all activities. The results indicate that activity employment levels, vehicle supply and the degree of trip chaining are among the principal determinants of transport provider trip frequencies for these activity groups. Elasticities of industry trip frequencies with respect to vehicle supply and trip chaining are in the ranges of .8 to 1.0 and .3 to .7, respectively. The significance of vehicle supply as a determinant of trip frequency is thought to reflect the impact of longer-term decisions firms make with respect to own-account transport provision upon the level of transport operations. Because the degree of trip chaining is determined by the interaction of the characteristics of transport pattern choice problems and constraints such as those of vehicle capacity and transport pattern duration, the finding that trip chaining is a significant determinant of trip frequency constitutes statistical evidence of the effect of these constraints on goods vehicle traffic volumes.

The major conclusion to be drawn from the industry trip attraction equations is that there is considerable variation in the shares of each industry's trips which are attracted to other industries per employee of the attracting industry. Nevertheless, the trucking and warehousing and wholesale trade sectors account for the largest shares of trips attracted per employee for trips provided by manufacturers, transport, trade, and all activities combined.

Another important finding of the empirical analysis is that of pronounced locational variation in the incidence of goods vehicle traffic. Trip attraction rates for each group of industry trips are highest at the center of the region and decline as a function of increasing travel time from the Boston CBD. Most of the locational variation in trip attraction rates, which is greatest for trips provided by trade, occurs within 45 minutes of travel time to the center of the region. This is the subarea at the region in which congestion is greatest and the traffic impacts of freight transport operations would be most severe. This finding is one reason why it may be important to improve planning for urban goods vehicle traffic.

The multinomial logit analysis of trip origin-destination linkages is performed on a subsample of the survey data consisting of trips made by manufacturers of food products within a fairly large subarea of the region. The empirical findings obtained are completely consistent with the hypotheses suggested by the proposed paradigm of the firm's vehicle routing behavior. A major finding is that factors in addition to the travel time from trip origins to alternative destinations influence trip origin-destination probabilities. In particular, the probabilities of choice among non-depot destination alternatives are influenced by the locations of the trip origin and the destinations in relation to the depot; these factors are also determinants of the savings in travel time that results from trip chaining. Another finding of note is that the choice of the depot as a trip destination is not influenced by its proximity to the trip origin. Rather, other factors, such as constraints on vehicle capacity and tour duration, which were omitted from the empirical analysis and represented by a constant in the model, may be the principal determinants of return trip linkages to the depot. However, in view of the limitations of testing hypotheses on one small data set, the assumptions needed to support the logit analysis, and the theoretical possibility that the empirical findings may depend on the specific characteristics of vehicle routing problems, no claim is made that these results are transferable to other contexts.

A number of overall conclusions and some recommendations for further research emerge from the theoretical and empirical analysis conducted in this study. These are summarized below.

(1) When judged in its entirety, the empirical work appears consistent with the general theory of urban freight transport behavior that was proposed. However, because of data limitations and various simplifying assumptions, disaggregate analysis of firms' transport pattern decisions is needed to substantiate, reject, or extend the findings obtained in this study.

(2) Analyzing the determinants of goods vehicle traffic from the perspective of transport providers leads to different substantive conclusions than have been reached from other modelling perspectives. A variety of factors omitted from previous studies were found to have significant effects on goods vehicle trip generation and distribution.

(3) Some of these factors, such as decisions on the supply and characteristics of goods vehicles and other aspects of distribution logistics, are of a

longer-term nature than transport pattern decisions. This supports the need to expand the scope of inquiry in future research to include these aspects of firm behavior.

(4) Trip chaining considerably complicates the relationship between the transport of goods and urban spatial structure. Because goods consignments are transported in multi-destination tours, there is no simple relationship between patterns of intraurban trade and flows of goods vehicles. However, at the micro level, decisions about trade flows are critical determinants of the alternatives and the choices for goods vehicle tripmaking. Consequently, a rather detailed level of data collection and analysis may be needed to support research on urban commodity flows and their relationship to the transport of goods.

(5) Trip chaining appears to be of considerable theoretical and empirical importance as a determinant of the generation and spatial distribution of goods vehicle traffic. Improved models for trip chaining are needed for further research on urban freight transport and improved planning models.

(6) The findings obtained in this study underscore the insufficiency of the models currently used to forecast goods vehicle traffic in urban areas. However, in view of the many complex theoretical and empirical issues involved, considerable research on urban commodity flows and urban freight transport may be required to provide an adequate basis for the reformulation of planning models.

Outline of the Remaining Chapters

The organization of the remainder of this study is as follows. Chapter 2, which begins by defining many of the terms used in this study, presents a review of the literature on the short-run relationship between urban spatial structure and the generation and distribution of urban goods vehicle trips. The chapter concludes with a discussion of major unresolved research issues.

A theory of the behavior of urban freight transport providers is presented in Chapter 3. First, the context for decisions firms make about goods transport is described. This is followed by a conceptual description of transport pattern choices which is used to justify a paradigm of the firm's trip chaining behavior. This paradigm suggests a variety of hypotheses concerning the determinants of urban goods vehicle traffic. Chapter 4 describes the application of the proposed theory to the problem of developing an approach for the empirical analysis of goods vehicle trip generation and distribution and their relationship to the activity system.

The empirical part of this study is presented in the next three chapters. Chapter 5 describes the setting for the empirical research including the Boston region and the data utilized in the analysis. The analysis of goods vehicle trip generation relationships is described in Chapter 6. Chapter 7 presents the analysis of the distribution of trips within complex vehicle trip patterns.

Chapter 8, which concludes the study, relates the main findings of this research and their limitations to suggestions for further research.

Chapter 2 Background and Literature Review

This chapter presents a review of the studies most relevant to this research and other pertinent background information. This review, which emphasizes studies of urban freight transport demand, is not intended to be exhaustive but to provide a critical examination of the most important findings obtained to date and to indicate issues in need of further research.

As will become evident, aspects of work on interregional freight transport, urban passenger travel demand, theories of location and trade, as well as many concepts and methods central to the fields of economics, geography, and operations research are also relevant to the study of the relationship between goods vehicle traffic and the spatial structure of metropolitan areas. Although it is clearly beyond the scope of this chapter to summarize the state of knowledge in these fields, an attempt has been made in this and subsequent chapters to note and to utilize aspects of this work.

This chapter is in three parts. First, some definitions and terminology are introduced which will be used throughout this report. Second, a critical review of prior studies of the short-run relationship between the transport of goods and urban spatial structure is presented. This includes an examination of modelling approaches and models which have been proposed for analyzing and forecasting urban freight transport demand. Lastly, major unresolved issues concerning the analysis of the relationship between goods transport and urban spatial structure are discussed.

2.1 Definitions and Terminology

The literature on urban freight transport contains a large number of terms and definitions which may often appear to have no common meaning. For this reason it is both desirable and necessary to define the terms which will be employed in this study.

We begin by considering the designation "urban goods movement". A comprehensive definition of urban goods movement has been suggested by the U.S. Department of Transportation (DOT 1973).

> "Urban goods movement is the transportation, and terminal activities associated with the movement of things as opposed to people in urban areas. It includes the movement of things into and out of the area, through the area, as well as within the area by all modes including the transmission of electricity to the extent it relates to transportation of fuels, pipeline movement of petroleum, water, waste, the collection and movement of trash and mail, service

> truck movements not identified as person movement, and even some person trips which involve the substantial goods movement such as shopping trips."

Urban goods movement is thus a broad designation which distinguishes the activities associated with the transport of goods from the transport of passengers for purposes other than shopping.

The above definition notwithstanding, some authors (e.g., Hicks, 1977) utilize the term "urban goods movement" to refer to the production, attraction, and spatial distribution of flows of goods rather than to describe urban freight transport mechanisms themselves. The distinction between goods flows and vehicle flows is fundamental and, to avoid confusion, the label "urban goods movement" will be utilized sparingly and as a general designator of both urban goods flows and goods vehicle movements, each of which will be carefully identified when it is desired to distinguish between them.

Commodity flows are the flows of physical products from producers or shippers to purchasers or other receiving activities. Goods are defined as the aggregate group of commodities produced, and shipped or distributed by a given industry group. Thus, as employed here, the use of the term "commodity" in place of the designation "goods" implies a greater degree of homogeneity in the character of the products so described.

<u>Goods shipments or consignments</u> are collections of goods which are transported together and which have identical (activity and spatial) origins and destinations. A single consignment may be comprised of a number of disparate products.

Urban goods flows and shipments are generally considered to be of two types depending upon the location of their respective origins and destinations. <u>Intraurban goods flows</u> are those with both their origins and destinations within the boundary of an urban area. <u>Interurban goods flows</u> have only one endpoint within a single urban area and thus refer to import or export flows.

Similarly, <u>intraurban freight transport</u> takes place wholely within an urban area, and <u>interurban freight transport</u> refers to the conveyance of imports and exports to and from urban areas. In this study we will concentrate on intraurban movements of goods vehicles recognizing, however, that the integration of studies of intraurban and interurban freight transport is not an inconsequential task for future research.

The flows of goods vehicles are typically measured in units known as trips. Current practice in many transport studies, as most recently prescribed by the U.S. Federal Highway Administration (FHWA), is to define a trip as "...one way travel from one place to another for a particular purpose which takes the truck outside the block in which the travel started" (FHWA, 1973, p. 150). Under this definition, shorter movements of a vehicle are amalgamated into a single trip which meets the prescribed distance criterion.

This accounting scheme also has the effect of increasing the incidence of trips on which more than one consignment is delivered or collected. For example, multiple deliveries occur on one trip when more than one establishment is served at the same location without a movement of the goods vehicle or, alternatively, when the distance between vehicle stops is less than either one street length.

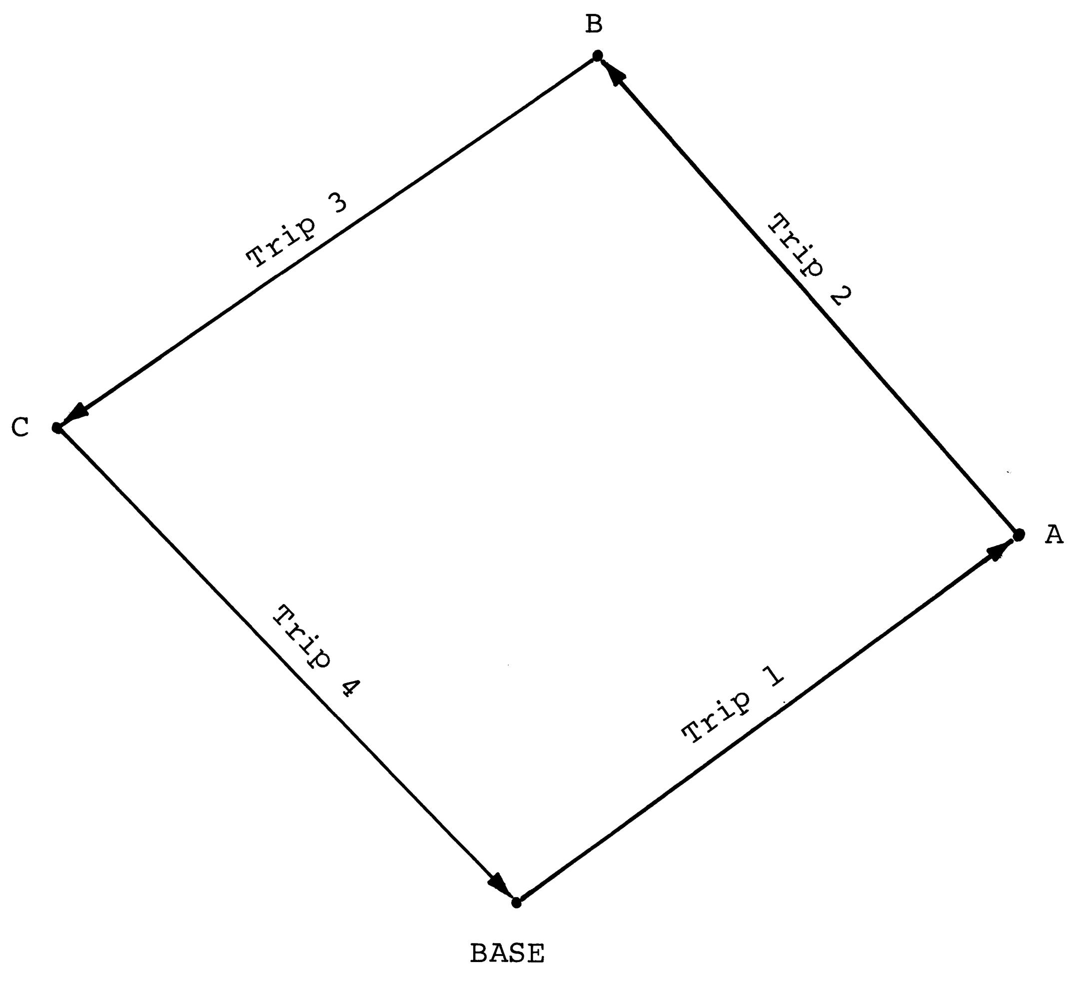
The distinction between one trip with two deliveries to different activities and two trips with one delivery each, is conceptually unappealing because it rests on an arbitrary spatial partition. Since multiple trips and multiple-delivery trips are substitute alternatives faced by firms in making vehicle routing and scheduling decisions, their relative incidence may vary with the characteristics of land use patterns and the transport system. As a result, this accounting scheme may introduce bias in the measurement of trip generation. For this reason, it seems preferable, at least for theoretical analysis, to consider a trip to be the movement of the vehicle and/or the driver-deliveryman from one stop to another no matter how short the distance may be.

Goods vehicle trips are made for a variety of purposes. Some trip purposes may not even be related to goods carriage which is the main topic of concern in this research. Important goods vehicle trip purposes include those of goods delivery and goods collection. These purposes, of course, are not mutually exclusive and there are multi-purpose trips on which goods are both dropped off and collected.

A fundamental characteristic of urban goods vehicle trips is that they are typically organized in tours comprised of two or more trips. For the purposes of this study, a <u>goods vehicle tour</u>, an example of which is shown in Figure 2.1-1, is defined as two more trips connected in a sequence which begins and ends at the same location. Thus, tours are defined by the origins and destinations of their component trips and should be distinguished from the actual network links or paths traversed by the vehicle. The point at which a tour originates is called the <u>base</u> or <u>depot</u>,

Figure 2.1-1

A Goods Vehicle Tour



which is somewhat analogous to the home-base designation used in referring to urban passenger trips. Note, however, that the base of the vehicle may be at a location remote from a tour origin.

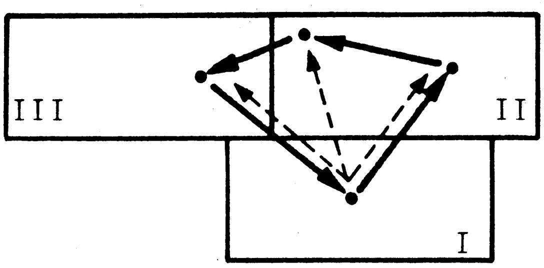
Goods vehicle routes or tours may be classified on the basis of the purposes of the trips which comprise them. It is important to distinguish four types of goods vehicle tours, delivery tours, collection tours, and two types of mixed pick-up and delivery tours. An example of each type of tour is shown in Figure 2.1-2.

In the figure, the bold, directed line segments which correspond to the trips in each tour have been overlaid on three traffic zones (denoted by Roman numerals). In the (pure) delivery tour, each of the first three trips are inbound trips on which goods will be dropped off. The origin of the goods flows is the origin of the tour in this case, and this is indicated by the dashed lines which represent the flows of goods. The last trip in a delivery tour (assuming the deliveries have been made) will be empty, and its purpose is usually described as "return to base" or by a similar phrase.

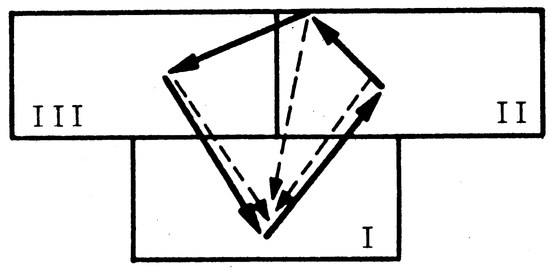
In a (pure) collection tour, consignments will be picked up at the destination of each trip except the last on

Figure 2.1-2

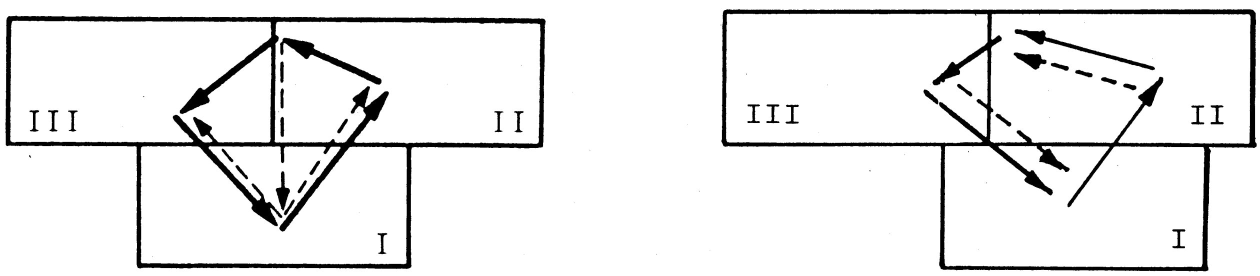
Major Types of Goods Vehicle Tours



DELIVERY



COLLECTION



MIXED PICK-UP AND DELIVERY

which the goods are dropped off at the base. Typically, the first trip will be empty and its purpose will be coded "from home base" in goods vehicle movement surveys. The flows of goods for collection tours originate from one or more sources and have a common destination. This pattern is the opposite of the goods flow pattern for the delivery tour.

Several different types of (mixed) pick up and delivery tours are possible, and two are shown in Figure 2.1-2. The first (lower left hand corner) is a hybrid in that it merely combines the elements of the delivery and collection tours. In the second (lower right-hand corner) although the pattern of vehicle trips is the same, the pattern of goods flows is more complicated with one consignment[1] having neither an origin nor a destination at the base in Zone I.

A fact which is evident from consideration of Figure 2.1-2 is that there may be considerable disparity between spatial patterns of goods or consignment flows and patterns of goods vehicle trips (Wood, 1970a, FHWA, 1973). By itself, the pattern of trips need not provide much information as to the goods flows accomplished. Similarly, goods flows are not likely to reflect nor indicate the tour the vehicle traverses (Hicks, 1977).

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[1]We assume that only one delivery is made on the indicated trip.

As suggested by Figure 2.1-2, there are a variety of ways in which the transport of the goods that firms purchase as inputs or sell as outputs may be accomplished. Consistent with the designations given to goods vehicle tours, one categorization of these alternative patterns of transport organization is that of delivery, collection, and (mixed) pick-up and delivery logistical systems.

A firm which operates under a pure delivery logistical system is one which delivers its products on its own account, but does not utilize the vehicles it owns or operates to collect any of its inputs. Similarly, a firm which operates under a pure collection logistical system collects its inputs with its own transport resources, but does not deliver its output which will be transported by for-hire carriers or other firms. Mixed logistical systems involve both pick-up and delivery operations and are characteristic of for-hire transport.

2.2 Previous Studies of the Relationship Between Freight Transport and Urban Spatial Structure

Several different types of studies have addressed the short-run relationship linking the urban activity system to the generation and spatial distribution of goods vehicle traffic. This topic first arose in the long-range metropolitan transport planning studies because of the need to forecast future levels of traffic of all types. This review begins by describing the models used in many of these planning efforts and examining an example of the truck trip generation and distribution models which typify the best contemporary planning practice.

A number of research studies have investigated the generation of truck trips at commercial and industrial establishments or land uses. These studies, which are discussed next, represent the principal body of knowledge on the determinants of urban goods vehicle traffic. Recognition of the limitations of both the planning models and the research studies led to a variety of proposals for improved modelling frameworks and models of urban commodity flows and goods vehicle traffic, and these are also reviewed in this section.

2.2.1 Planning Studies

Analytical consideration of the relationship between the transport of goods and urban spatial structure dates from the earliest metropolitan transport studies undertaken in the U.S. following the Second World War. The first explorations were largely confined to simple tabulations, but, in the landmark Detroit study (Hamburg, 1953), an attempt was made to provide a crude explanation of the levels of goods vehicle trips originating in each traffic zone. There, and subsequently in the Chicago Area Transportation Study (CATS, 1959), goods vehicle trip generation for specific land uses was assumed to be proportional to person trip generation. This approach was supported by the argument that person trips were more adequate measures of human activities than land use. The alternative approach, that urban goods traffic be viewed as a function of activities or land use, was most prominently articulated by Mitchell and Rapkin (1954). This became the dominant view implemented in most post-1960 urban transportation planning studies which included commercial vehicle movements.

Mitchell and Rapkin

In an extensive monograph which treated both passenger and goods traffic, Mitchell and Rapkin (1954) laid the foundation for many of the subsequent studies of urban freight transport. Among the important points articulated were: (1) the goods movement system requires separate analysis because "its nature is quite different from that of persons movements" (p. 89); and (2) the level of analysis should be the establishment or a meaningful grouping of establishments-geographic, sectoral, or otherwise and should take account of the disparate nature of activities.

Mitchell and Rapkin noted the important distinction between goods flows and truck movements. They suggested that goods movement by truck would vary among similar establishments as: (1) a function of the utilization of other modes, and (2) as a function of consignment sizes which might be correlated with fewer stops per truck or the utilization of larger vehicles. Absent data with which to pursue these ideas, the empirical work conducted by Mitchell and Rapkin was limited to regression of the number of trucks stops against total nonresidential floorspace for 33 CBD origin and destination traffic zones in Philadelphia using data from a 1949 survey.

Hill

Hill (1965) formally proposed the sequence of models for predicting truck traffic which has become the standard urban transportation model system (UTMS) approach typically utilized in the larger metropolitan planning studies. When less data are collected, rather more primitive modelling approaches have been suggested (Wilson, 1974).

The proposed methodology, identical to that employed in the analysis of passenger travel, entailed the construction of goods vehicle trip generation equations estimated by ordinary least squares and the utilization of a gravity model for predicting trip distribution. It was suggested that goods vehicle traffic be partitioned into light and heavy vehicle classes.

In an apparent analogy with the UTMS logic for passenger travel, Hill (p. 173) suggested that truck traffic was determined by the four interrelated decisions indicated below:

"(a) Why transport goods
(b) When to transport goods
(c) How far to transport goods
(d) How to transport goods"

In Hill's schema, the question of how far to transport goods was a matter of trip distribution, and the issue of how to transport goods was identified with the frequency and distribution of trips by vehicle type. Apart from the above description, however, Hill did not discuss the nature of these decisions or identify the hypothesized decisionmakers.

Hill's work has been noted here to provide historical perspective. The limitations of the UTMS approach do require consideration, however. A general critique of the

UTMS approach which applies to Hill's work as well as to a more sophisticated application will be provided next in the context of the discussion of the models developed by Saunders (1973).

Saunders

Work carried out at the Greater London Council (GLC) toward the development of internal goods vehicle trip generation and distribution models reported by Saunders (1973) represented an attempt at a thoughtful and careful application of the traditional UTMS approach. Goods vehicle trip generation and trip distribution models were developed at two spatial scales - 186 districts and 933 traffic zones - utilizing data from the 1962 London Travel Survey.

Several trip generation equations were developed for light goods vehicle trips to industrial land uses, light goods vehicle trips to non-industrial land uses, and heavy goods vehicle trips to all land uses. Separate equations were developed for trips with destinations within the London County Council and for those terminating outside this area. The reason given for this strategy was the hypothesized differential effect of impediments to goods vehicle movements and parking within the central area.

Based in part on the findings of Starkie (1967) to be discussed shortly, both linear and log-linear models were estimated. Also given as a reason for the log-transformed equations was the presence of biased residuals for many of the untransformed equations. The regression results which were reported are given in Table 2.2-1. (Estimates of the equations shown with coefficients represented by the "a_i" were not reported.)

The method used to specify and estimate the trip generation models was stepwise regression. Moreover, variables with insignificant coefficients were summarily dropped from the equations. Together, these procedures led to the disparate and seemingly _ad hoc_ specifications of the trip generation models. It is difficult to comprehend, for example, why the number of households in a district should influence the number of light goods vehicle trips to industrial land uses.

Apparently only activity variables were considered for inclusion in the model equations. Note that transport supply variables are absent from all the equations that were developed. As a result, forecasts made utilizing these models would be completely insensitive to any transport policies which might be introduced.

Table 2.2-1

Greater London Council District Trip Generation Equations

LCC Area	R^2	Pattern of Residuals
*Log(LGVNI) = 1.38083+.00883HH+.04372RC+ .09484Log(RG)+.37415Log(OS)	.89	R
LGVNI = a_0+a_1HH+a_2RC+a_3RG+a_4OS	.90	B
*Log(LGVI) = .44835+.00911HH+.21861Log(MAN)+ .35539Log(OS)	.76	R
LGVI = a_0+a_1HH+a_2MAN+a_3OS	.79	B
*Log(HGV) = .97528+.00591HH+.26257Log(MAN)+ .03895Log(WH)+.29906Log(OS)	.87	R
HGV = a_1+a_2HH+a_3MAN+a_4WH+a_5OS	.83	NA
Outer Area		
Log(LGVNI) = a_0+a_1HH+a_2RC+a_4Log(RG)	.85	B
*LGVNI = 90.21442+.10862HH+.28541RC+.10178RG	.89	B
*Log(LGVI) = .62046+.01154HH+.05250RC+ .03815Log(MAN)+.44818Log(OS)	.82	R
LGVI = a_0+a_1HH+a_2RC+a_3MAN+a_4OS	.83	B
Log(HGV) = a_0+a_1HH+a_2Log(RG)+a_3Log(MAN)+a_4Log(OS)	.85	B
*HGV = 23.98708+.06855HH+.18479RG+.03595MAN+ .47148WH	.87	B

Dependent Variables

LGVNI=Light goods vehicle trips to non-industrial land uses

LGVI=Light goods vehicle trips to industrial land uses

HGV=Heavy goods vehicle trips

Independent Variables

HH=households

RC=Employment in retail convenience activities

RG=Employment in general retail activities

MAN=Manufacturing employment

WH=Employment in wholesaling

OS=Employment in other services

*Considered the best equation

R=random
B=biassed

a_i=coefficient not reported

The basis for the comparison of the transformed and untransformed equations was the coefficient of determination and the absence of bias in the residuals. However, the comparison of the respective coefficients of determination was invalid because the dependent variables were not equivalent for the equations compared (Rao and Miller, 1971). For this reason, it is difficult to accept or reject Saunder's work as providing empirical evidence as to appropriate functional forms for aggregate models of goods vehicle trip generation.

Saunders is to be commended for considering the extent to which her models conformed to the assumption of the least squares model. Saunders' test for homoscedasticity was to observe the plot of the residuals against the corresponding values of the dependent variable. As is indicated in Table 2.2-1, many of the trip generation equations which were estimated were characterized by biased patterns of residuals.

Potential relationships between the independent or left-out variables and the residuals were not investigated, although these relationships, if present, would also constitute violations of the assumption of constant variance of the residuals. This omission would seem particularly serious in view of the fact that all of the variables in all of the equations were dependent on the size of the districts. As Douglas and Lewis (1970b, p. 430) have pointed out, "when such variables are used it can be expected that the magnitude of the equation or residual error will be related to the zone size." This suggests that it is possible that improved models could have been developed utilizing rate variables.

Inspection of the equations for the inner and outer areas of the region indicates differences in trip generation rates. An hypothesis suggested by this result is that goods vehicle trip generation rates vary with location. It would seem desirable to investigate this hypothesis with improved models of goods vehicle trip generation.

Implicit in the formulation of separate equations for trips made by different vehicle types is the assumption that levels of heavy and light goods vehicle trips are independent of one another and depend only on the mix of activities. An alternative hypothesis, which was not considered, is that the generation of trips made by different classes of vehicles are interdependent, and that at least some of the factors influencing the relative proportion of vehicle trips of different types are amenable to analysis.

Saunders also estimated zonal trip generation models following the same approach. It was reported that (p. 11) "not only were the coefficients of the equations different but also that the levels of explanation were poor." Comparison of the district and zonal equations revealed that different functional forms and model specifications seemed best for the district and zonal equations, respectively. No discussion was offered on this point, but it seems fair to comment that this does not build any confidence in the GLC models.

Goods vehicle trip distribution models of the standard doubly-constrained gravity type were calibrated at the zonal level for the same three categories for which the trip generation models were constructed. It was noted that terminal costs comprise a substantial component of delivery costs and, in the absence of data, two minutes were added to the beginning and end of the off-peak (interzonal) travel times utilized in the gravity model "cost function". This would have to be considered an *ad hoc* procedure in view of the absence of evidence that terminal times influence the spatial distribution of goods vehicle trips and the fact that terminal times measured elsewhere (Keefer, 1963; Christie *et al.*, 1973a) were larger than those employed in the GLC models.

Although good syntheses of the observed trip length distribution were obtained. Further scrutiny of the predicted cell values for light goods vehicle trips revealed inordinate disparities between observed and synthesized flows. Significantly, the ratios of the synthesized to observed flows were no closer than .25 for 65% of the cells in the trip distribution matrix for which non-zero flows were both observed and synthesized. Fully "54% of the cells of the synthesized matrix had trips distributed to them despite zero interchanges in the observed matrix" (p. 21). Although it was not recognized by Saunders, it is thought that this result is likely to be a direct consequence of the trip chaining which is characteristic of urban freight traffic, as will be discussed in subsequent chapters.

Quite apart from the critique that has been offered, it is essential to recognize the importance of Saunders' empirical work. Its significant contribution is that it provides tangible evidence of the difficulties and the limitations that may be associated with the UTMS approach. Prior applications of the approach typically failed to subject their results to any of the appropriate statistical tests. Unless there is cause to consider the GLC work as an isolated case, it seems reasonable to entertain the possibility that deeper investigation of virtually all of the goods vehicle models in use would lead to similar findings. Further work will be required to uncover whether these limitations were the result of insuffficent data, site-specific factors, methodological oddities, or more fundamental theoretical problems.

2.2.2 Business Premise Traffic Generation

Recognition that non-residential land uses were important traffic generators (Schuldiner, 1966) led to a series of investigations of the traffic generated by commercial and industrial establishments. Early studies of business premise traffic generation emphasized person travel (Black, 1966; Kolifrath and Schuldiner, 1967) or analyzed the generation of different traffic types by combining them in the common units of passenger car equivalents (Latchford and Williams, 1965; Ackroyd, 1966).

Despite this limitation, the business premise traffic studies were not without influence upon subsequent work. The major contributions of these studies were that they furthered the ideas that (1) traffic at non-residential sites was important (Watson, 1975), (2) that analysis at the disaggregate level of individual establishments was both feasible and fruitful, and (3) that different activities have different trip generation rates. An outgrowth of studies of person trip generation at non-residential land uses were studies whose primary emphasis was on truck trip generation.

2.2.3 Establishment Truck Trip Generation Studies

Starkie

Perhaps the most influential study of goods vehicle trip generation was that performed by Starkie (1967). This study is generally considered innovative 1) because it was disaggregate and 2) because Starkie investigated an alternative to the linear functional form of truck trip generation models. Because Starkie's approach was adopted by other researchers, his work and its limitations will be reviewed in some depth.

Starkie analyzed the generation of trips from 77 manufacturing plants located in the Medway towns (in Kent). At the time of data collection (1964), the Medway towns were an important engineering centre suggesting that they exported a considerable volume of goods to other regions. This may lessen the relevance of Starkie's research to intraurban freight transport.

A diverse array of manufacturing establishments were surveyed. There were, however, 37 firms in engineering and allied trades and data for this group of plants were used in a subset analysis. One of Starkie's important findings was that trip generation was influenced by the type of manufacturing activity, similar trip rates being observed from plants in the same SIC groups.

Starkie's quantitative analysis entailed the estimation of a variety of simple, univariate regression models relating the daily volume of goods vehicle trips observed at these plants to measures of employment and floorspace. No distinction was made between goods vehicle trips bringing inbound shipments of freight and those transporting the output of the manufacturing establishments. Starkie's trip generation equations are shown in Table 2.2-2.

Examination of the data and comparison of the coefficients of determination for the linear and log-linear models led Starkie (op. cit., p.33) to conclude that disaggregate "commercial vehicle trip generation, at least in terms of manufacturing employment and floor space-area, is basically curvilinear; the rate of increase in trips declining as the size of industrial plant gets larger, thus indicating 'economies of scale' in trip generation." Although this hypothesis is intuitively reasonable, Starkie's empirical evidence is, unfortunately not sufficient to support his conclusion. One reason is that,

Table 2.2-2 Starkie's Trip Generation Equations

Dependent Variable, Y	Number of Observations	Regression Equation	R^2	Independent Variables
Goods Vehicle Trip Generation in:				
1. All Manufacturing Establishments	77	Y = 26.96+.0377E (.0076)	.25	E = Employment
2. " "	70	Y = 19.44+.0003F (.0000)	.37	F = Floorspace
3. " "	77	LOG Y = .2568+.5595LOG E (.0601)	.54	
4. " "	70	LOG Y = -1.1749+.5714LOG F (.0564)	.60	
5. Engineering and Allied Trades Subsample	37	Y = 21.83+.0343E (.0047)	.60	
6. " "	37	LOG Y = .4010+.4996LOG E (.0332)	.87	

as noted previously, the comparison of coefficients of determination for regressions with different dependent variables is invalid. There are also numerous other deficiencies in the analysis and its interpretation which merit consideration.

In order to explain the presence of economies of scale in trip generation, Starkie interpreted the positive constants in the equations to indicate that there was a basic minimum volume of traffic associated with all plants, and that "an increase in plant size has its effect mainly by changing the load factors of vehicles already scheduled to call at the plant. [Examination of vehicle loads associated with the survey plants suggests that there is plenty of scope for increasing loads" (p. 34).]

This interpretation of the constant term is incorrect in that the constant represents the effects of other variables which are relevant but were omitted from the equations (Rao and Miller, 1971). The potential list of left-out variables is large, and this is probably the most serious deficiency of Starkie's analysis. Omitted from the model specifications were measures of freight mode split; the number, size, and operator of the goods vehicles making trips to and from the plants, the proportion of inbound and outbound trips or consignments, and consignment sizes. On theoretical grounds, each of these factors may be an important determinant of trip generation and could provide an alternative explanation for Starkie's finding.

One possibility is that large plants ship and receive goods by other modes such as rail and barge (apparently both prevalent in the Medway towns) to a greater extent than small firms. A study by Buhl (1967), based on data collected in the 1963 U.S. Census of Transportation, found that the intercity motor freight transport share of manufacturing firms (for outbound shipments) varied with plant size for each of wide range of manufacturing industries.

Although Starkie observed that activities with high average trip generation rates (per employee), had high proportions of heavy goods vehicle trips to total goods vehicle trips, he completely ignored the possibility of a relationship between the proportion of heavy goods vehicle trips and trip generation rates for firms within the same industrial codes. This is rather surprising since one would expect that larger firms would make larger purchases of inputs many of which would be delivered in large vehicles and would use large vehicles (and thus fewer outbound trips) to distribute their output. This behavior would directly explain Starkie's conclusion that there are fewer trips/employee generated at larger plants.

Starkie's explanation of his findings rests on the implausible assumption that the schedules of arriving vehicles are both fixed or stable and independent of the size and timing of orders made by firms. In this regard, his identification of load factors rather than consignment sizes is misleading. Clearly there may be increases in the size of the firm's purchases and thus in the size of shipments delivered without there necessarily being a corresponding increase in the number of vehicle trips. Increases in consignment size may lead to an increase in observed percentages of vehicle capacity utilized when delivery is made at a given plant, but it is also possible that decreases in load factors could also result, if larger vehicles are utilized. In any case, making inferences about vehicle load factors at intermediate stops when vehicles make many deliveries on each tour is fraught with danger. Thus, we note that Starkie's parenthetical contention with respect to the scope for increasing vehicle loads is problematical and belies his failure to consider the presence of trip chaining as a feature of freight transport behavior.

It is unfortunate that Starkie did not consider the effect of trip chaining, as it is apparently a major method by which economies of scale in urban goods transport are achieved. In fact, it is easy to see that the consolidation of many (outbound) consignments into a single outbound goods vehicle trip might help to explain Starkie's measurements if it could be shown that the degree of trip chaining increases with firm size. A theoretical argument to this effect will be presented in Chapter 3.

Trip chaining implies a clear distinction between tour generation and trip generation. If the majority of the outbound trips were actually the first links in multiple-trip tours, then Starkie's data collection procedure measured tour generation in many cases instead of trip generation. If the aim of the study was to assess the traffic impacts of industrial activity, then this procedure leads to a systematic underestimate of trips produced by the establishments and fails to capture trip generation in locations remote from the plant itself.

A final conceptual problem with Starkie's models stems from his failure to deal with the firm behavior which governs goods vehicle trip generation. In his defense, Starkie did recognize that changes in production and inventory strategies might lead to variation and/or change in trip generation parameter estimates. However, somewhat surprisingly, he suggested, that "in the short-run, commercial vehicles will probably exhibit a fairly rigid trip/production relationship and a high degree of inelasticity in their demand for the use of road space" (p. 25).

Therefore, Starkie would have us believe that trip generation is independent of the firm's spatial pattern of goods purchases and sales, the supply of goods vehicles, vehicle routing and scheduling behavior, and transport costs. By implication, commercial vehicle trip generation would be completely unaffected by any transport policies and strategies. For these reasons, although Starkie's research was an important study for focusing attention on goods vehicle trip generation, it is clear that it was seriously deficient in several respects.

Wallace

With the aim of investigating the determinants of the location of manufacturing plants and especially the role of industrial/linkage, Wallace (1971) conducted a in-depth study of the characteristics of freight traffic surveyed at 78 manufacturing plants in the Northwest Midlands. Although it seems reasonable to view Wallace's research as explicitly interurban in character, given the choice of manufacturing industries and empirical findings with respect to the length of trip/transport linkages, several aspects and findings of Wallace's work are particularly relevant, if only by analogy, to the study of urban freight transport.

Following Starkie, Wallace (op. cit., p. 105) also estimated log-linear trip generation equations for four groups of manufacturing establishments concluding that a simple disaggregation by industrial category can yield recognizable benefits for planning purposes by increasing the accuracy of industrial traffic prediction." Arguably, it would be desirable to investigate this conclusion more fully by examining the possible effects of a wide variety of variables omitted from Wallace's equations which could possibly account for the variation in the trip generation rates of activities.

Although these factors were not included in the quantitative analysis, Wallace was sensitive to the fact that firm decisions and management policies with respect to production and transport were determinants of traffic characteristics. He used management interviews to investigate some of the more important issues. What emerged from the discussion of the findings was the rather substantial diversity of behavior with respect to logistical arrangements, pricing policies, and traffic operations.

Evidence concerning the relative incidence of different logistical arrangements suggested that the majority of trips made by manufacturers' own vehicles were outbound trips making deliveries of output; most of the trips made by other firms to the plants surveyed were inbound trips. Of particular relevance to the study of intraurban goods transport was the finding that some firms make deliveries on their own account for shipments up to a certain distance and use public hauliers for long distance transport.

An interesting and important feature of Wallace's work was that he obtained data on the pricing policies employed. Diversity of attitude and behavior was once again the rule rather than the exception, but it was noted that delivered pricing was the most common arrangement. Further, there appeared "to be a fairly strong connection between the use of the manufacturers' 'C' License fleet and delivered pricing" (p. 143).

Wallace called attention to the potential importance of freight transport speed and reliability as determinants of industrial linkage. He noted that physical proximity was not a prerequisite for a high degree of transport quality (level of service) and that at least some products which required rapid and reliable transport were traded over long distances. Well-organized transport arrangements (high frequencies made this possible) could be more satisfactory than the haphazard arrangements which might characterize short distance linkages.

Wallace performed a variety of tabulations of trip lengths looking for differences in mean hauls that might be attributed to the type of transport provision, the direction of shipment, the stage of production, the size of the vehicles, and vehicle load factors. Although Wallace recognized the existence of intermediate stops in road goods transport, the implications of trip chaining on his research strategy and findings were apparently not considered. Unfortunately, it appears that many of the findings with respect to the distribution of trip lengths could be as easily explained by the presence of trip chaining and its confounding effects on measurement as by the traditional factors cited by Wallace.

Redding

Redding (1972) performed a study of vehicle trip generation at 87 electrical engineering and 105 clothing industry plants located in northwest London. Data were collected by survey for a period of five working days and included information on all non-work vehicular movements to and from each plant.

Redding found substantial differences in tabulated data in both the characteristics of firms and in trip generation rates for the two industry groups. For both activities, however, an extremely high degree of uniformity was found in the daily levels of trip generation. The minimum daily share of the weekly (5-day) total was never less than 18% nor more than 21% for either industry group. However, greater variation existed for locationally selected subgroups of each industry.

Redding estimated trip generation equations in which total vehicle trips and commercial vehicle trips were the dependent variables. Alternative explanatory variables tested (with stepwise regression) in univariate and multivariate equations included floor space, total employment, manufacturing employment, distance from Charing Cross, number of goods vehicles, and the number of company cars. Of these, the first two variables were found to account for most of the variance explained in all the estimated equations, and employment was found to perform somewhat better as an explanatory variable than floorspace. Although other variables were occasionally found to be significant when entered as independent variables in conjunction with employment or floor space, it was stated that the other variables added little explanatory power or significance to the overall relationship. It is possible however that the importance of these other factors could only be discerned with a more logical grouping of trips.

Results for the multivariate equations were not given. The statistical quality of the univariate relationships was modest with coefficients of determination in the range of .61 to .79 for electrical engineering trip generation and between .36 and .38 for the clothing industry models.

Guided by Starkie's findings, Redding also utilized log-linear regressions to test for the presence of a non-linear relationship between trip generation and firm size. However, Redding found that no improvement was obtained, leading him to conclude, (p. 172) that "simple linear regressions of trips per week on total employment or total floor space would be the most appropriate form of expressing the traffic generation of these industrial groups." For reasons given previously, it is impossible to judge the validity of comparison. Redding's study is obviously very similar to the research performed by Starkie and Wallace and is subject to many of the same criticisms.

Maltby

Maltby (1973) performed a study of traffic generation at manufacturing establishments in Sheffield and Manchester, England. The stated aim of the study, which built upon prior work by Maltby (1970) and others, was to consider "more rigorously than hitherto the question of similarities in trip rates over different manufacturing activities and geographic areas, and of the choice of explanatory variables" (p. 21).

Separate models were developed for light and heavy goods vehicles and this may have significantly impacted the results, as might the practice of not distinguishing between inbound/outbound trips or those provided by the establishment on its own account. In comparing paired sets of linear and log-linear equations, Maltby evidenced a preference for the former arguing that in view of the unavailability of appropriate explanatory variables it seemed futile to make the mathematical form of the models more complex.

Experimentation with a broader set of explanatory variables was confined to different classification of employment (total, male, and female) and different types of floorspace (total, production office, storage, other). The explanatory power of these different variables was compared by an analysis of variance. Production floorspace was found to be the "best" explanatory variable for heavy commercial vehicle movements.

Comparison of trip generation rates for different geographic areas was limited to one SIC order—VI engineering and electrical industries in Shefield and Manchester. There was some indication of a similarity in trip generation rates. However, the sparseness of this analysis does not provide a sufficient basis for ascertaining the effect of location or accessibility upon trip generation.

A "comparison of regressions analysis" was conducted to identify similarities in traffic generation rates for different SIC orders. The findings are indicated below.

> "The comparison of regressions analyses suggested that common relationships could be used over all eight different manufacturing activities for 'light commercial vehicle movements' and 'business attractions'. In other words there was evidence of similarities in traffic generation rates over these different activities. On the other hand, the comparison of regressions analyses indicated a distinction in traffic generation rates for heavy commercial vehicle movements over the different manufacturing activities" (p. 29).

Common relationships were also indicated for heavy commercial vehicle movements when a distinction was made for heavy and light industrial groups. However, in general the models constructed explained only a small percentage of the variance in trip generation rates. Whether the similarities would be found in improved models is an open question.

Leake and Gan

Leake and Gan (1973) analyzed the generation of vehicle trips from plants in road haulage and four wholesaling activity groups. Total (undifferentiated) commercial vehicle trips were modelled as a function of one variable from a set which included floor area, non-office floor area, site area, and employment. Linear, parabolic, geometric, and exponential functional forms were tried, albeit without any theoretical justification. Apart from these differences, the method of analysis paralleled that employed by their predecessors and is subject to the same criticisms which will not be repeated here.

The findings were that linear and parabolic functions gave the best fits, and that the best explanatory variable varied with the activity group. In no case was employment the best explanatory variable. "This is not surprising since the particular industrial groups covered in the study are concerned with the distribution of various types of goods and these, of course, require storage and loading/unloading areas, etc." (Leake and Gan, op. cit., p. 353).

Meyburg and Stopher

Meyburg and Stopher (1973) analyzed trips attracted[2] to retail stores in shopping centers in upstate New York.[3] In the analysis, manhours worked and total floor area were utilized (separately) as explanatory variables in linear, semi-log, and log-linear regression models for trips attracted to all stores, speciality stores, supermarkets, and the overall shopping centers. The significant relationships obtained were those linking total floor area and manhours worked to trips to each shopping center and to supermarkets. Coefficients of determination for most other models were very low. The log-linear models had slightly higher coefficients of determination, but they were not strictly comparable for reasons given previously, thus obviating the conclusiveness of the result.

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[2]It was found that a negligible number of outbound trips were produced.

[3]Other studies of trips to commercial activities were performed by Christie et al., (1973a, b) at the Transport and Road Research Laboratory. A fairly extensive review of the literature concerning retail deliveries and the problems associated with the use of heavy goods vehicles for this purpose is provided by Smith (1975).

2.2.4 Studies Including Urban Goods Flows and Consignments

Although the importance of analyzing intraurban trade as the basis for explaining goods vehicle traffic is generally acknowledged, studies of urban freight transport demand have made little progress toward this end. In those studies which made attempts to take this deeper view, inquiries were often limited to measuring the volume (tonnage) of goods or the number of consignments generated by or attracted to different activities of land use. In many of these studies simple tabulations of data constituted the analysis undertaken.

In an early study, Horwood (1959) measured deliveries to several types of centre city activities in Philadelphia. His findings suggested substantial seasonal variation in the receipt of goods shipment, but little variation in annual patterns. Hoel (1963) analysed the delivery weights of shipments transported by for-hire vehicles. Hoel (1963, p. 143) concluded that "within each land use category, the average weight of commodity delivered shows a fairly consistent pattern when stratified by axle type. The greater the number of axles, the heavier is the average weight of commodity delivered."

Masson (1970) reported results from a partially completed analysis of the urban areas of Aix-en-Provence and Metz-Thionville, the former primarily a residential community, the latter a heavily industrialized area. By analyzing deliveries to retail shops and discounting for differences in fuel consumption as a result of climate, Masson found that roughly the same tonnages of goods were required to serve the same number of people in either area. He noted as well that food and petrol accounted for more than half the total tonnage received by retail shops.

Wood (1971) reported on a survey of goods vehicle movements and commodity flows within the developed area of the Tri-State Transportation Region. The data indicated that goods-vehicles moved 73% of the total internal freight tonnage and accounted for 97% of total freight costs. Approximately one–half of all freight carried by trucks was destined for commercial enterprises while the other half was consumer-oriented.

Bates (1970) examined the weights of deliveries to various activities within the central area of Toronto and several other Canadian cities. He found significant variations in the weight per shipment associated with different land-use categories.

In a study with broader aims, Hitchcock, Christie, and Cundill (1974) obtained data on the tonnage and commodity composition of the deliveries to different land uses in Swindon. Together, crude minerals and building materials accounted for more than 40% of the total weight dropped; this finding provides a sharp contrast to truck trip data which illustrates that high trip generation rates are usually associated with retail and residential land uses (Wilbur Smith and Associates, 1969).

Several studies of urban freight transport demand have attempted to analyze both urban goods flow and the associated goods vehicle trips. Although these studies fell considerably short of linking the demand for urban freight transport to the demand for goods, they represent the initial attempts in this regard and are especially valuable for this reason.

Watson

Watson (1975) presented an analysis of consignment generation and goods vehicle trip generation for a sample of only 12 manufacturing plants in the Chicago-area cities of

Evanston and Skokie, Illinois.[4] A more detailed account of a portion of this study is given by Gaudio and Meko (1973).

In spite of the urban location of the firms surveyed it is difficult to accept Watson's study as representative of urban goods movement. One reason is that the small number of data points is probably insufficient to support empirical conclusions. Another reason is that, as reported by Gaudio and Meko, 72.4% of the shipments originated or terminated outside the Chicago Metropolitan Area and were thus distinctly interregional in character.

Using the analysis method common to the prior establishment studies, total truck trip generation was regressed against total employment, total floorspace, and various subclassifications of these measures. Briefly, it was concluded that (1) total employment and total floorspace performed similarly as explanatory variables; (2) disaggregating floorspace and employment variables was not a useful strategy; and (3) log-linear models performed bettter than simple linear regressions. The latter conclusion was

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[4]Of thirty firms approached, 17 refused to participate in the survey and one of the responding firms was dropped because it was adjudged to be unusual in terms of its attributes and operations. This rate of refusal suggests that data collection for urban freight transport studies may be subject to greater difficulties than are typically encountered in surveys of passenger travel behavior.

based on the invalid comparison of the coefficients of determination, and thus is of unknown validity.

Separate models were also developed for inbound and outbound trips. Interestingly, linear rather than log-linear models were presented, although no reason was given for this inconsistency with the total trip models.

The most innovative feature of Watson's research was the construction of the shipment generation models shown in Table 2.2-3. Log-linear models were also tried, but were thought to offer no improvement. The equations illustrate a substantial difference in the rates of consignment generation (outbound shipments) and consignment attraction (inbound shipments).

The data collected made it empirically feasible to analyze the relationship between truck trips and consignments and this could have been the most important contribution of the research. However, Watson did not construct a model of outbound truck trips as a function of outbound shipments and offered no explanation for this omission of the so-called "vehicle loading" model. Close inspection of the data revealed a high degree of variability in the ratio of shipments (especially outbound) to truck trips. This may have discouraged model building efforts.

Table 2.2-3

Watson's Shipment Generation Models

Model	R^2
TS = 13.97+.0044TF (t=8.66)	.88
TS = 17.92+1.666(TE) (t=7.31)	.84
IS = 35.64+.0007TF (t=4.51)	.67
IS = 32.65+.308TE (t=5.02)	.72
OS = 21.67+.0036(TF) (t=9.02)	.89
OS = 14.73+1.357(TE) (t=6.97)	.83

Dependent Variables

TS = Total Shipments

IS = Inbound Shipments

OS = Outbound Shipments

Independent Variables

TF = Total Floorspace

TE = Total Employment

Potential relationships between trip and shipment frequency were investigated utilizing the method of canonical correlation. The analysis was restricted to data for only two firms and the method employed was correlative rather than causal in orientation. The following results were reported.

> "the results on the shipment truck models are not altogether satisfactory in the sense that no clear-cut relationship between shipment and truck characteristics emerges from the analysis. Nevertheless, there are indications that weight and volume adequately characterize a shipment and that this combination is correlated with truck type and capacity variables." (p. 82)

It was suggested that the latter finding might provide a basis for developing a vehicle loading model.

<u>Ogden</u>

Ogden (1977a) performed a descriptive study of goods flows utilizing data derived from a truck survey for Melbourne, Australia. The importance of distinguishing between goods flows and goods vehicle trips was borne out by the finding that there was substantial variation in the sizes of consignments resulting in a considerable disparity between tonnage and trips generated.

Ogden (1977b) presented the results of an empirical investigation of both goods flow generation and truck trip generation using the same data from Melbourne. Although it appears that it would have been possible to attempt to model truck trip generation as a function of goods flows, this opportunity was not taken; Ogden stated that "both truck trip and freight generation models are developed independently" (p.106).

Aggregate zonal truck trip generation attraction equations were estimated for each of seven different trip purposes. Included among the purposes were home base, pick-up, and retail delivery. This particular stratification splits up the trips made in multi-purpose transport patterns and does not correspond to any grouping of the behavioral units producing goods vehicle trips. The trip generation and attraction models also had slightly different specifications of explanatory variables. This seems hard to justify; because goods vehicle trips occur in tours, there tends to be an equal number of trips produced and attracted at each activity for each purpose in each zone. This suggests that it makes more sense to model trip ends or to model productions or attractions and set the other equal to it.

Models explaining the attraction of goods (in tons) to zones were also estimated with ordinary least squares.[5] Some dissatisfaction was expressed with these models because of the low degree of explanation obtained and, more importantly, because of the difficulty of incorporating "social, technological, political and economic factors." Ogden recognized the importance of improving the models but was pessimistic about the prospects.

Ogden apparently made no attempt to model goods generation. If for no other reason, this might have afforded a check on the adequacy of the data. Although this might have been feasible with the data, models of the spatial distribution of commodity flows or of vehicle trip generation as a function of commodity flows were not attempted. Apparently, empirical studies of these aspects of urban freight transport demand have yet to be carried out.

2.2.5 Proposed Modelling Approaches and Models

The limited empirical work on urban goods transport demand has lead to a recognized need to develop models and modelling approaches to be used for analysis and forecasting

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[5]Ogden refers to these models as commodity generation models, but his definition is actually one of goods attraction.

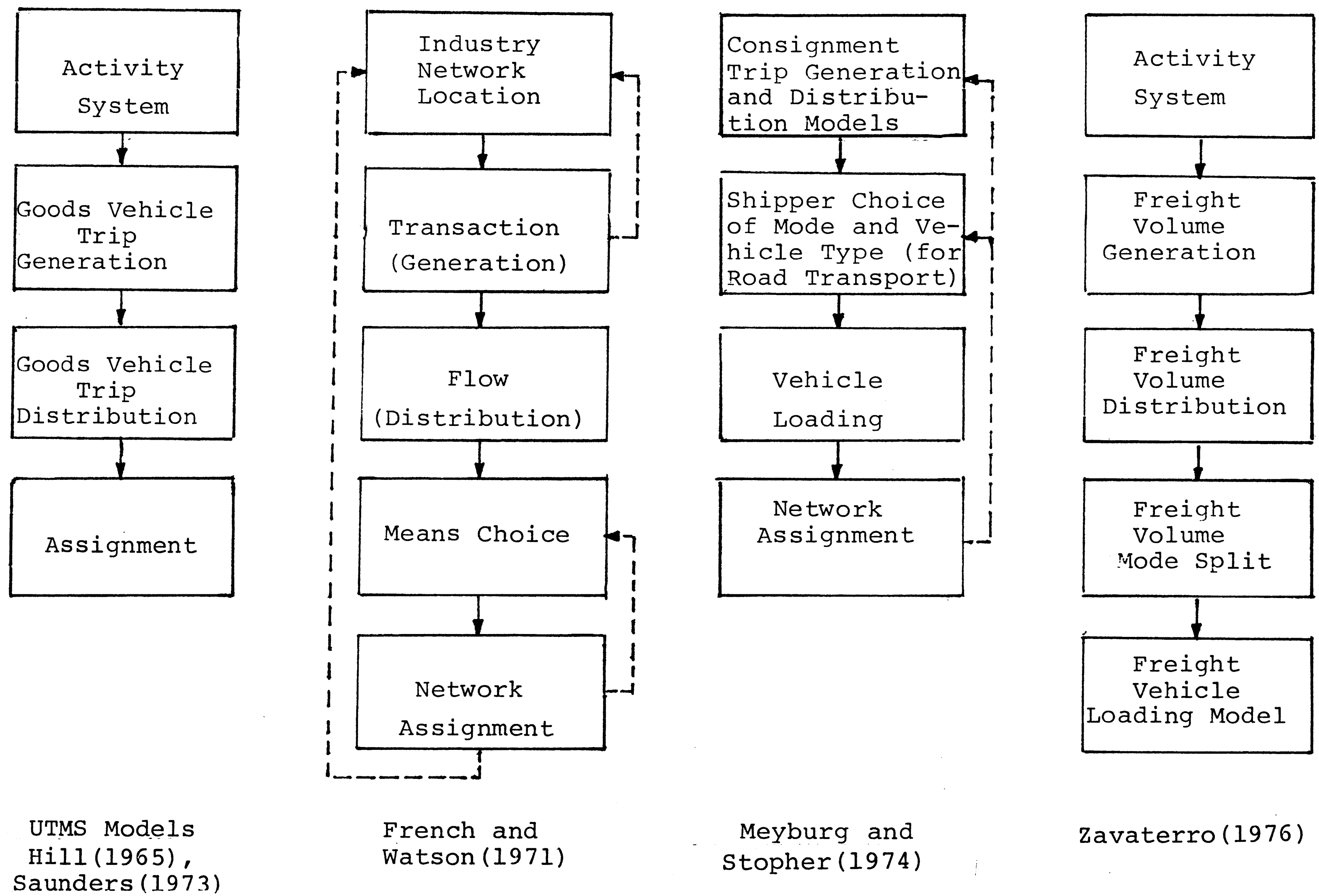
(Hedges,1971a; French and Watson, 1971). A variety of proposals for modelling frameworks and component models have appeared in the literature, and these will now be discussed.

Modelling Frameworks

Four modelling frameworks proposed in the literature are depicted in Figure 2.2-1. Of these, only the UTMS sequence (for trips) has been fully implemented in empirical work (as described previously).

The remaining frameworks represent an advance in that they each attempt to base urban freight transport demand on the demand for goods. Common elements of all three are a two-stage approach to freight flows which separates generation and distribution and also separate models relating transport variables to freight flows. Although it is not apparent from the terms employed, the means and mode choices were defined to include the utilization of vehicles of different types. The framework proposed by French and Watson (1971) was thought to be applicable to both micro and macro scales and useful for modelling flows associated one good or industry or an entire urban area (Hedges, 1971a). Meyburg and Stopher (1974) proposed disaggregate (micro) analysis and focused on the importance of the consignment, suggesting that it was the appropriate unit of analysis of

Figure 2.2-1 Modelling Frameworks



freight flows. The macro scale framework specified by Zavaterro (1976) addressed freight flows in terms of the generation, attraction, and spatial distribution of volumes of commodity flows.[6]

Apart from the choice between micro and macro approaches which should involve analytical considerations, the modelling frameworks lead to obvious and important questions about the interrelationships, structure, and specification of the various submodels. Various model structures for the analysis of urban freight transport have been proposed either independently or as further articulations of the modelling frameworks introduced. In keeping with the literature, in which other alternatives have not been considered, we shall discuss prospective models of goods flows and goods vehicle trips (to be based on goods flows) separately.

Models of Urban Trade Flows

Models proposed for the representation and analysis of urban trade flows include simplified aggregate general equilibrium models and both aggregate and disaggregate

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[6]This is the familiar conceptualization found in studies of intercity freight flows (such as Black, 1972; or Chisholm and O'Sullivan, 1973) which emphasized generation and distribution.

(microbehavioral) partial equilibrium models.[7] A general equilibrium framework for analyzing trade flows would be attractive because patterns of different commodity flows are not independent.

Input-output models are potentially operational general equilibrium models of urban commodity flow (Richardson, 1972) and several versions of these models have been suggested for this purpose. Hutchinson (1974) and Demetsky (1974) suggested the use of a single-region model to give overall estimates of regional commodity production and consumption. Romanoff (1973) proposed an extension of an existing single-region model to estimate goods generation by subarea. Macgill (1976) developed a full spatial model of intraurban trade, which incorporates a conservation of materials constraint, by refining Wilson's (1968) reformulation of the Leontief and Strout (1963) interregional input-output model. Because these models rely on highly simplified assumptions concerning the determinants of trade flows, it is not obvious how valid or useful they would be when applied to the metropolitan scale. In any case, the

[7]All of these models were initially developed for the purpose of analyzing interregional trade. Other models proposed for analyzing interregional trade which have not been suggested as prospective models of intraurban trade are not considered in this review. Prominent among these omitted models is the so-called transportation problem of linear programming (Kresge and Roberts, 1971, and Chisholm and O'Sullivan, 1973).

resource and data requirements for even the simplest input-output models are enormous, and this has seemingly precluded their use in the analysis of the relationship between goods transport and urban spatial structure.

The major alternatives to I-O models for trade take a partial equilibrium perspective, treating supply-demand equilibrium in the market for a single commodity or commodity group. As suggested by Demetsky (1974), Hutchinson (1974), and Zavaterro (1976) the gravity model[8] has been most often proposed for explaining and forecasting patterns of intraurban goods flows. At best, however, the gravity model is an overly simplistic and highly deficient theory of urban trade flows.

The main premise of the gravity model is that distance, travel time, transport costs, or some other measure of spatial separation is a principal determinant of spatial patterns of commodity flows. However, intraurban trade takes place over extremely short distances, and it is well-

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[8]The application of gravity models in the study of spatial interaction of various types has been extensive (Wilson, 1974). Applications of the gravity model approach to interregional commodity flows are to be found in Leontief and Strout (1963), Polenske (1970), Black (1972), and Chisholm and O'Sullivan (1973) among many others. Gravity goods vehicle trip distribution models have also been applied to external (interregional) truck trips. See, for example, Helvig (1964) or Byler and O'Sullivan (1974).

known that distance related costs are only a small component of freight transport costs (Bayliss and Edwards, 1970; Saunders, 1973). For this reason, it would seem that transport costs would be expected to have only minimal effects on patterns of trade.

Perhaps the most serious deficiency of the gravity model are the factors which influence trade flows which are onitted from its specification. Studies of local industrial linkage support this contention and the point made above; these studies also provide a more realistic view of the determinants of trading patterns and the problems of developing credible models.[9] For example, in a study of the linkages of manufacturing firms in metropolitan Montreal, Gilmour (1974, p. 357) obtained evidence that the factors rated most important in the choice of sources of inputs were "delivery reliability (the only factor regarded as important for every transaction), delivered price, and quality of product." A major finding was "that proximity to supplier was almost unanimously considered to be unimportant" and this correlated with the fact that for only 40% of the transactions was the known minimum cost alternative selected.

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[9]Similar findings on a related problem have been obtained in recent studies of destination choice for shopping trips (Burnett and Prestwood, 1975).

Many studies provide clearcut evidence that the importance of local industrial linkages varies significantly with the characteristics of firms including their size and location (Hoover and Vernon, 1962; Chinitz, 1961; Keeble, 1968; Townroe, 1974; and Lever, 1974). These findings also pose a direct threat to gravity and other aggregate models of trade and suggest the need for alternative approaches.

A third approach to modelling urban trade, proposed independently of the research cited above, but which is potentially responsive to the above criticism, is a disaggregate model of urban commodity flows. A starting point for a microbehavioral approach to freight demand, which builds upon recent advances in disaggregate modelling of urban travel demand and intercity freight transport mode split,[10] is provided in the work of several investigators at the Massachusetts Institute of Technology (Terziev, Ben Akiva, and Roberts, 1975; Terziev, 1976; and Roberts, 1977) and Cambridge Systematics, Inc. (Roberts and Kullman, 1976).

The basic idea is that shippers (or receivers) make joint choices from a set of alternatives of the origin,

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[10]Basic references on the application of disaggregate, probabilistic models of discrete choice behavior to urban travel demand include Charles River Associates(1972), Ben Akiva(1973), and Domencich and McFadden(1975). Disaggregate probabilistic models of freight mode split include Bayliss and Edwards (1970) and Hartwig and Linton (1974) reported in Watson(1975).

shipment size, and mode for consignments. The decision maker selects that alternative which conveys maximum utility (subject to uncertainty), where attributes of transport, commodities, the decision-maker, and the market enter the utility function. Under appropriate assumptions governing the functional form of the choice model and the utility function, it is possible to estimate the probability that a given alternative will be selected. Among the advantages claimed for this disaggregate approach are its behavioral base, improved model specification leading to greater policy sensitivity, efficient use of data, and parameter estimates which are free of the distributions of the explanatory variables.

Implementation of the disaggregate approach requires identification of the relevant decisionmakers, the scope of their decisions, and the alternatives they consider. Each of these problems is decidedly non-trivial. Several of the MIT studies cited, for example, have taken conflicting positions as to whether the identity of the decisionmaker is the shipper (producer) or the receiver (consumer) of goods. If a for-hire carrier is also involved, one or more of the choices of interest may be made by yet another entity. Clearly the logic, upon which the disaggregate behavioral approach rests, falls apart if one cannot match decisionmakers with the alternatives they face and the decisions they make. Apparently, there are quite formidable conceptual and empirical problems with disaggregate modelling of freight flows as well as with the other proposed approaches.

Models Relating Goods Vehicle Trips to Freight Consignments

One of the most important issues in developing a framework suitable for the empirical analysis of urban freight transport demand concerns the nature of the relationship between goods vehicle trip patterns and freight consignments. This is the province of the so-called "vehicle loading" model indicated in modelling frameworks of Meyburg and Stopher (1974) and Zavaterro (1976) and also mentioned by Watson (1975).

Apart from the points made by Watson (1975) noted previously, Meyburg and Stopher (1974, p. 76) provide the only substantive description of the role of the vehicle loading model, which, because of its brevity, is cited in its entirety below.

> "it remains to be established how these numbers of consignment movements by mode can be translated into vehicle flows on the transportation network. This is the objective of the vehicle loading model mentioned previously in this paper. It does not appear that the need for a vehicle loading model has been explicitly recognized in the area of urban goods movements, nor

does it have a strict analogy in the passenger transportation areas. (Automobile occupancy is the closest analogy, but it is far simpler than vehicle loading in freight demand analysis.) Therefore, any statements on the components and structure of the model are somewhat speculative. The model should be capable of providing estimates of both the number of loaded and partially loaded vehicle movements and the number of empty vehicle movements. The translation of consignment movements into vehicle movements will probably be related to the availability, by capacity, of vehicles, the characteristics of the consignment, the proportion of vehicle capacity required by each consignment and the total volume of consignments from each shipper in a specified time period, ability to hold up shipments until a full vehicle load is achieved, and characteristics of the desired pickup and delivery pattern of the vehicle. (One vehicle may pick up small packages from many destinations, particularly a for-hire carrier, whereas others may serve one origin and many destinations.)"

Curiously, the determination of the vehicle trip origin-destination patterns seems only an afterthought in the above discussion. We submit that trip generation and distribution should be a primary objective in modelling goods vehicle traffic and that the other objectives given above may be of lesser importance. Clearly, there is a great deal of work to be done in developing theory and models of the relationship of goods vehicle trips to shipment patterns.

2.3 Conclusion: Unresolved Issues in the Analysis of Urban Goods Vehicle Traffic

The preceding review has indicated a variety of issues whose investigation seems central to developing an improved understanding of the relationship between goods transport and urban spatial structure. These issues include the choice of analytical framework, the consideration of urban freight transport behavior, trip chaining, and the nature and scope of the factors that influence urban goods vehicle traffic.

2.3.1 Analytical Framework

As evidenced by the review of prior studies, empirical studies have failed to quantify either the relationship between vehicle trips and goods flows or the relationship between goods flows and regional spatial structure. Both these tasks are required to explain the impact of changes in the location and character of economic activity upon goods vehicle traffic (Meyburg and Stopher, 1974). A prerequisite is the identification of an appropriate framework or structure within which the transport of goods can be related to the activity system.

Although the analytical frameworks described previously provide a reasonable starting point, further theoretical work will be required. Basic questions which need to be addressed include the perspective to be taken, the scope of the problem, and issues concerning its internal structure.

Among the various perspectives relevant to urban freight transport demand are those of the goods producer, the goods consumer, and the supplier of transport. In prior disaggregate studies there appeared to be a presumption, as evidenced by the data collection and analysis undertaken, that it was sufficient to examine freight demand from a single perspective. Unlike the situation which arises in studying urban passenger travel behavior, the exchange of goods typically involves the behavior of at least two distinct behavioral units (the shipper and receiver) and possibly a third (the supplier of transport). This difference may require that a more complex framework will be required for the analysis of urban freight transport demand.

The scope of the required analysis is also at issue. Decisions which influence or are interdependent with deicisons about urban freight transport should be taken into account. Existing modelling frameworks have failed to incorporate important decisions firms make, such as those about vehicle ownership and fleet characteristics or logistical arrangements, which are obviously related to the demand for urban freight transport. Moreover, the modelling frameworks have been less than explicit with respect to the attributes of goods vehicle traffic which are to be addressed. This suggests that there is a need for a deeper examination of the scope of an improved analytical framework.

A third set of issues concerns the structure of the modelling framework itself. The modelling structures proposed in the urban freight transport literature are all recursive (sequential), although they differ somewhat in terms of the sequence chosen and the manner in which the overall relationship between goods transport and urban spatial structure is partitioned. Although a sequental model structure simplifies estimation problems it may be unrealistic and lead to misleading conclusions concerning the determinants of transport demand (Ben Akiva, 1973; Williams and Senior, 1977). Clearly, the structure of any model system for urban freight transport must be justified on theoretical grounds and this has not yet been done. A consideration generally absent in prior studies which could provide a basis for the formulation of an improved analytical framework is that of the underlying behavior and decision processes.

2.3.2 Urban Freight Transport Behavior

A striking omission in previous investigations of the relationship between the transport of goods and urban spatial structure has been the failure to define, describe, or otherwise address explicitly the behavior which governs urban goods vehicle traffic. Consideration of urban freight transport decision-making is required to avoid gross inconsistencies between models and reality; even if this were not a problem, it would be expected to be an obvious source of potential insights into the topic at hand. A prerequisite for the introduction of a behavioral base for studies of urban freight transport is the identification of the relevant actors and decisionmakers.

To suggest that there is an urban freight "industry" is somewhat of a misnomer, for as Wood (1970a, p. 26) pointed out, "nearly everyone moves his own freight." In other words, most goods are transported within urban areas by firms whose primary business is not that of providing transport services. The substitution of private carriage for for-hire transport for long distance shipments has been a strong and growing trend in the U.S. and in Britain, and, at the intraurban scale, the dominance of private versus for-hire carriage is even more marked. In the Tri-State Region, for example, Wood (1970b) found that less than 25% of total tonnage was transported by for-hire carriers. Similarly, truck trip statistics indicate "for-hire transport" sector movements are only a small percentage of the total in most American cities (Wilbur Smith and Associates, 1969). An indication of the ubiquity of urban freight transport provision is, as shown in Figure 2.3-1, that most of the trucks in local operation in the U.S. in 1963 were in fleets of only one vehicle.

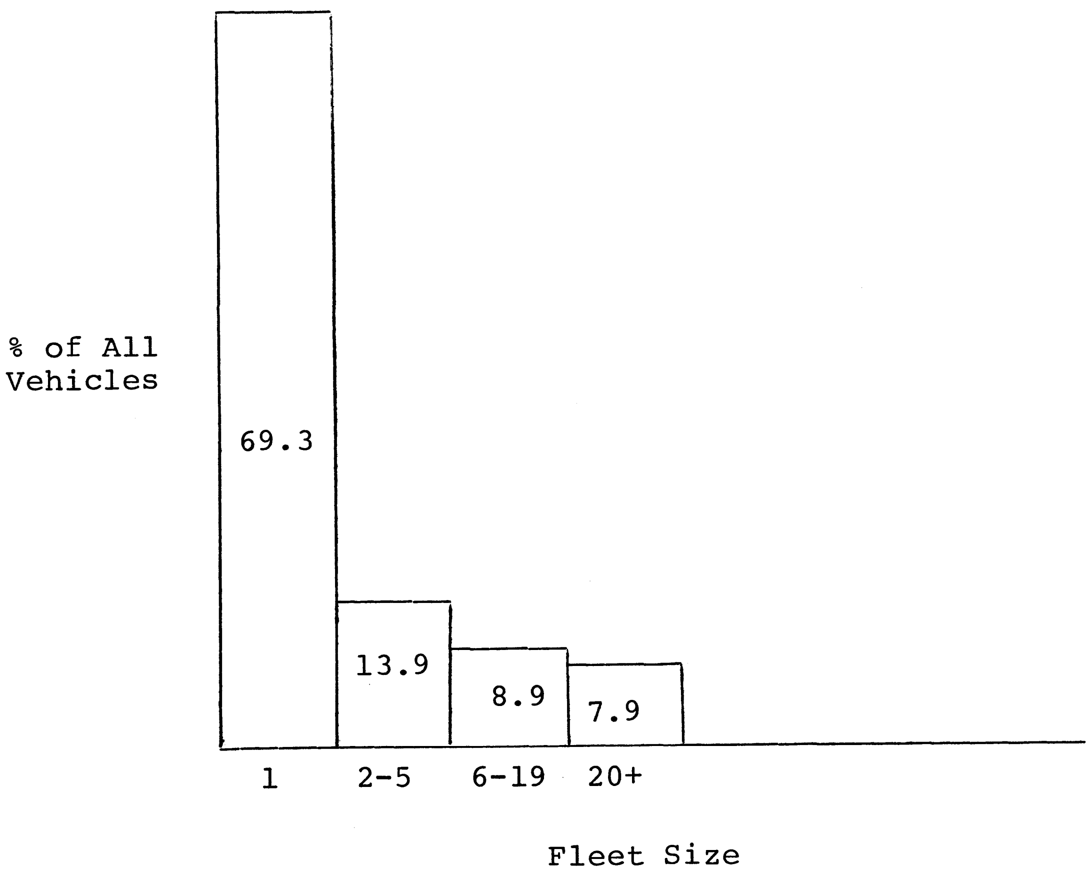
If we wish to examine the behavior that underlies urban freight transport, a logical place to begin is with behavior of urban freight transport providers. This would represent a departure from prior research studies which cannot be said to have collected or analyzed data from this perspective. In measuring trips attracted to plants, the disaggregate studies discussed previously collected data from a perspective most closely associated with that of a goods consumer. However, outbound trips were also generally included and these trips were typically provided by three different types of transport providers - (1) for-hire, (2) private carriage provided by other firms and (3) own-account transport. This is likely to be an important reason why behavioral issues were not confronted and may account for some of the reported difficulties in empirical modelling.

Theoretical and practical studies of distribution management problems have considered many aspects of the decisions faced by firms in delivering and collecting goods. These studies appear to provide a useful starting point for examining urban freight transport behavior and its consequences.

Figure 2.3-1

Distribution of Fleet Sizes for Vehicles

in Local Operations



Source: U.S. Census of Transportation (1963)

An operational transport problem faced by all firms that engage in the delivery and collection of goods on their own account is the determination of efficient routes for their vehicles. As a normative question, this problem has received extensive attention in the operations research literature.

The problem of determining the shortest route for the delivery of a set of shipments from a single supply point to specified destinations when their total amount is less than the capacity of a single vehicle is known as the "travelling salesman problem" (Dantzig, et al. 1954). An important generalization of the travelling salesman problem of particular relevance is the truck-dispatching problem, posed by Dantzig and Pamser (1959). The truck dispatching or vehicle routing and scheduling problem as it is often called involves the designing of vehicle routes for supplying known demands (specified by amounts and destinations) from a single depot with a fleet of vehicles of known capacity. The constraints imposed in the most commonly encountered variant of the vehicle routing and scheduling problem are that all the customer demands are to be filled and that the capacity (in terms of weight or volume) of each vehicle not be exceeded.[11] The aim of these journey planning problems is to find a set of routes that minimizes the total distance travelled, the total cost of distribution, or a related objective function.

The formulation of the vehicle routing and scheduling problem indicates many of the basic short-run decisions made by the suppliers of urban freight transport. These decisions include choices of tour and trip frequency and the spatial and temporal sequencing of trips.

The behavior, then, that we need to examine in detail in order to understand the demand for urban freight transport is that exhibited by establishments in making vehicle routing and scheduling decisions. Of course, we do not expect that these decisions are conceptualized by dispatchers as mathematical programming problems. However, since the problems have been studied extensively, it does seem reasonable to investigate the usefulness of the findings with respect to the problems considered in this research. Consideration of actual practices employed by firms is also indicated and both these tasks are undertaken in Chapter 3.

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[11] There may also be constraints on the duration of each vehicle journey pattern and the timing of deliveries.

2.3.3 Trip Chaining

An important feature of urban freight transport, almost universally ignored in prior studies of the relationship between goods transport and urban spatial structure, is the prevalence of multi-trip, multi-tour transport patterns. These complex vehicle trip patterns appear to be the direct result of vehicle routing and scheduling behavior, and they pose a direct challenge to existing transport demand theory.

Scant empirical evidence exists regarding the presence of firm's complex goods vehicle trip patterns. Disaggregate data on trip patterns traversed by a firm or establishment's vehicle fleet does not, to the best of our knowledge, appear to have been collected in urban transportation studies or research investigations. Although ample data exist on the trips made by individual vehicles during each day, these data have not been subjected to much analysis.

One of the few references to vehicle trip patterns is given by Wilbur Smith and Associates (1969) in their study of trucks in urban areas. Table 2.3-1 illustrates the diversity of trip and tour generation for various activities.

Table 2.3-1

Examples of Daily Urban Truck Trip Patterns

Vehicle Operator	Vehicle Type	Times Leaving Home Base	Addresses Visited before Returning to Home Base
Service Station	Pickup	4	1
Furnace Repair	Pickup	1-2	2-4
Dry Cleaner	Panel	1-2	14
Auto Parts Dealer	Pickup	6	1-2
Milk Retailer	Multistop Van	1	100-125
Telephone Service	Panel	1-2	10-15
Lumber Company	Flat Bed	3	1-3

Source: Data for Cincinatti, Ohio reported in Wilbur Smith and Associates (1969,p.21)

In ignoring the phenomena of trip chaining and multi-tour vehicle transport patterns, prior models of urban goods vehicle trips have implicitly assumed that each goods vehicle trip is independent of all others made by the same transport supplier or vehicle. There can be no question that this assumption is invalid, and its violation suggests the possibility that serious biases exist in current urban goods vehicle trip models.[12]

A simple example may serve to illustrate this point. Figure 2.3-2(a) illustrates a vehicle delivery tour on which goods are transported from zone i to zones j and k. Assume that the vehicle is fully loaded when it departs from the depot and that each delivery is of the same size. It is further assumed that over some interval of time, the level of demand at j and k doubles.

What then will be the new vehicle trip pattern? We submit that application of current models of trip and generation and distribution would predict the pattern (b). Clearly, pattern (c) is preferable, and its selection requires little sophistication on the part of a decision-maker.

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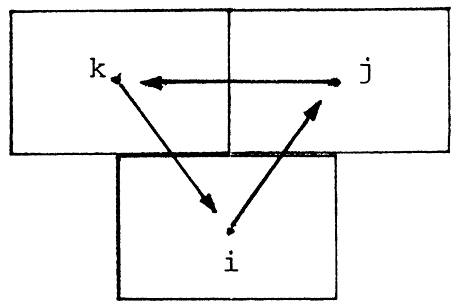
[12]Arguments to this effect, in the context of the urban passenger travel demand literature, are given by Adler (1976), Jones (1975), and Hensher (1976).

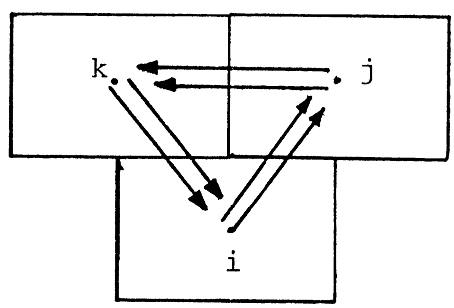
Figure 2.3-3

An Example of the Possible Effects of Trip Chaining

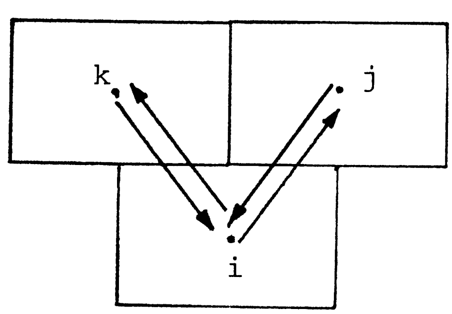
(a)



(b)



(c)



Conventional models of trip end generation would predict a doubling, or at least an increase, in the trip ends for each zone where, obviously, an increase may not be required. The implications for trip distribution are even more striking in that increases in demand at j and k lead to a decrease in the volume of trips connecting j and k. In fact, no trips are required at all. This example suggests that the impact of trip chaining may be considerable in that responses to small changes in customer locations, demands, vehicle capacity, network travel times and other factors may result in substantially altered patterns of vehicle traffic (at least at the disaggregate level). Seemingly, prediction of the impacts of transport policies upon goods vehicle traffic would appear to require an ability to treat trip chaining with analytical or empirical models.

In comparison with the neglect of this problem for freight transport, considerable and growing attention is being given to the importance of multi-purpose and multi-destination urban passenger travel (Jones, 1975). These studies are an obvious source of insight and hypotheses, but since they pertain to a different form of transport, it is suggested that any promising analogies be considered cautiously.

There are several modelling approaches to trip chaining which have been explored in the urban passenger travel demand literature. Extensive and up-to-date reviews of this literature are provided by Jones (1975), Adler (1976), Hanson (1977), Hautzinger and Kessel (1977), and Massachusetts Institute of Technology (1978). Unfortunately, the most common characteristic of studies of urban travel linkages has been their descriptive rather than explanatory focus. Despite some notable attempts (especially Adler 1976), satisfactory models which can account for and predict complex journey structures do not exist, and it is thought that considerable new theory and models will be required to accomplish this objective (Jones, 1975). Nevertheless, some important theoretical ideas have been advanced which may be relevant, and these will be discussed in subsequent chapters.

2.3.4 Factors that Influence Urban Goods Vehicle Trip Generation and Distribution

A general problem in need of a great deal of further work is the empirical investigation of the factors that influence urban goods vehicle traffic. Prior empirical studies have generally limited their choice of explanatory variables in trip generation models to a sparse set of activity system measures. As a result, prior work leaves generally unaddressed or unanswered questions as to the role and significance of the activity system, commodity flows, transport supply, costs and technology, and other factors as determinants of urban goods vehicle traffic.

The Activity System

The most significant finding established in previous empirical studies is that different activities have different goods vehicle trip generation rates. This work needs to be extended to ascertain the relative contributions of different activities to urban goods vehicle traffic and to explain the degree to which the various characteristics of activities including intensity, location, accessibility, and vehicle supply influence trip generation rates.

One particular deficiency to be remedied is that the trip generation of many of the activities which appear to make the largest relative contribution to urban goods vehicle traffic have not been subjected to much analysis. For example, very few disaggregate studies have analyzed trip generation by trucking and warehousing activities. Aggregate models have typically omitted measures of activity in this and other employment categories suggesting serious problems in forecasting and possible bias in model coefficients. As a result, a great deal remains to be learned concerning the major generators of goods vehicle traffic.

Because the demand for freight transport is derived from the demand for goods, the impact of the goods purchased and sold by activities is clearly one, if not the most, important determinants of vehicle traffic to be quantified. Because of data limitations, intensity measures such as employment have been used as proxies for measures of goods flow in trip generation analysis. Consequently, an important unanswered question is whether or not these different trip rates are primarily the result of variation in the volume or weight of goods shipped and received by different activities or whether other factors are at work. If the generation of goods vehicle traffic is well explained by the generating and consuming propensities of activities, then simpler and more accurate forecasting procedures than those currently employed might be developed.

Another issue on which contradictory evidence was obtained in prior work is the presence of scale effects in the relationships between trip generation and activity levels. Because differences in trip generation rates may be attributable to many factors such as vehicle ownership, trip chaining and consignment sizes, careful empirical work will be required to make progress in exploring this question. It is not difficult to suggest theoretical reasons why characteristics of activities other than intensity like the spatial attributes of location and accessibility might also influence the demand for goods vehicle trips.

The rationale for the hypothesis of the presence of locational variation in urban goods vehicle traffic generation stems from the basic interdependence of location, trade, and transport. Theories of intraurban location indicate that the location of the firm is a major determinant of the size and spatial extent of its market area (Richardson, 1971). Location also effects the choice of suppliers to the extent that accessibility and transport costs are among its determinants (Lever, 1974).

Spatial variation in transport network characteristics and in the distribution of supply and demand points[13] may also introduce locational variation in goods vehicle trip generation and distribution. One possibility is that it is relatively more efficient to serve multiple collection and delivery points in central locations where there is a higher density of activity. In these locations, market thresholds are of considerably smaller spatial extent (See Isard, 1956,

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[13]Central place theory and urban location theory indicate that the location of activities within metropolitan regions is distinctly non-uniform (Berry, 1967; Alonso, 1964).

p. 271) than at lower densities, and the distances between customers are relatively short. At locations where the possibilities of serving more than one customer on the same route are slight, there is an increased inducement to economize on trips and achieve higher load factors, particularly when the line haul component of transport costs is large.

The Supply of Urban Freight Transport

The decisions firms make with respect to goods purchases, consignment sizes, and goods vehicle trip patterns are not independent of the supply of goods transport, the limitations of urban freight technology, and the various performance/cost tradeoffs permissible among the feasible alternatives. The supply of goods transport is determined by a variety of factors including the characteristics of vehicle fleets, the road transport network, and other fixed facilities, and demand patterns. Although theory accords an important role to supply as a determinant of traffic patterns (see, for example, Manheim, 1977), transport supply measures have been almost totally absent from trip generation models.[14] Clearly, an

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[14]Hutchinson (1974) presents several univariate models which suggest that vehicle supply explains at least some of the variation of goods vehicle traffic at manufacturing plants.

understanding of the role of transport supply is required to develop and to evaluate planning strategies.

Road freight transport has a distinctive technology whose characteristics and constraints have been seemingly ignored in prior attempts to relate goods transport to urban spatial structure.[15] Included among the important constraints upon the operation of goods vehicles are physical limitations of vehicle capacity, roadway and parking regulations, and labor work rules leading to temporal constraints on journey duration. Since many of the policies contemplated for urban areas will modify or augment constraints upon vehicle operation, it would seem particularly important to incorporate these constraints in theories and models of goods vehicle traffic.

2.3.5 Concluding Remarks

As indicated by the preceding discussion, there are many serious and unresolved issues concerning the short-run relationship of the transport of goods to urban spatial structure. In view of the magnitude of the conceptual problems involved, it appears that a considerably improved

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[15]This omission stands in contrast to studies of urban freight consolidation in which the importance of these constraints is fully recognized.

theoretical basis is needed to account for the generation and distribution of goods vehicle traffic in urban areas. The development of an improved theory of urban freight transport is the principal objective of the next chapter.

Chapter 3 A Disaggregate Theory of the Determinants of Urban Goods Vehicle Trips

This chapter proposes a disaggregate theory of urban freight transport behavior. This theory suggests a set of hypotheses which describe the determinants and outcomes of the urban freight transport decisions made by firms and is intended to provide the basis for an empirical assessment of the factors that influence urban goods vehicle traffic.

Conceptually urban freight transport demand can be thought of as derived from the demand for the goods and services that activities produce, consume, and exchange. For this reason, activities' basic decisions about location, production, consumption, and trade are fundamental determinants of urban goods movements. Firms also make a wide variety of distribution logistics decisions including the use of proprietary and for-hire road transport, the ownership and supply of goods vehicles and consignment mode choice. These complex decisions, which set the context for urban freight transport pattern choices, are discussed in the first part of the chapter (3.1).

In the short-run (i.e., with its location, trade, and logistical system fixed), the firm makes its basic transport pattern choices. The short-run transport pattern choice can be thought of as the daily (or other temporal unit with behavioral significance) choice of the consignments to be transported and the routing and scheduling of the vehicles under the firm's control.

The second part of the chapter presents a conceptual description of transport pattern choices. First, a brief overview is given of the dimensions of transport pattern decision problems and the procedures employed by firms in solving them. Trip chaining is hypothesized to be a principal outcome of transport pattern choices, and this is illustrated with a simple numerical example. Second, a conceptual description of the factors hypothesized to determine transport pattern decisions is presented in terms of the firm's preferences, transport pattern alternatives, and the choice process employed. This discussion provides the basis for a simplified representation of transport pattern decisionmaking which, it is concluded, is needed to support further theoretical analysis of urban freight transport behavior.

This analysis is contained the third part of the chapter which presents a paradigm of firm behavior in which the firm's transport pattern decisions are viewed as resulting from the application of rational solution procedures to the vehicle routing and scheduling problem assuming that the consignments to be transported have been predetermined. Utilizing and building upon some results from the operations research literature, the paradigm suggests "behavioral" hypotheses characterizing the outcomes of transport pattern decisions and their determinants. Among the characteristics analyzed are tour and trip frequencies, transport pattern distances as a function of shipment lengths, the costs of urban freight deliveries, and the spatial patterns of goods vehicle trips.

3.1 The Context for Urban Freight Transport Decisions

Decisions about location, production, trade, and transport are made by firms, plants, institutions and households. These micro-economic entities are therefore the behavioral units whose decisions must be considered in providing a theory which relates goods vehicle transport patterns to urban spatial structure.

Since the main concern in this research is goods vehicle trip generation and distribution and since decisions about goods vehicle movements are typically made by the firms or decision units within firms which produce commercial goods transport in urban areas, the firm will be the behavioral unit of major interest.[1] However, the behavior of other decision units such as households is also of interest as they, too, contribute to urban freight transport demand, primarily as consumers of goods and services produced by firms and institutions.

The major choices firms make about location, production, trade, and transport distribution logistics are based partly upon transportation technology, costs, and supply and, in turn, are fundamental determinants of the firm's transport choices. Figure 3.1-1 provides a rough categorization of these choices as long-run, medium-run, and short-run decisions.[2] Typically, short-run decisions are made more frequently than longer-run decisions. All of the choices are potentially important in influencing short-run urban freight transport behavior. However, because these choices are extremely complex, their structure can only be outlined.

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[1]Other or more complex behavioral units may exist in the case of multi-establishment firms or vertical integration in production or distribution. Further, it should be recognized that the locus of the decision-making unit within the firm may vary considerably from firm to firm.

[2]The identification and classification of choices is very crude in that the variety and complexity of firm behavior is substantial (Cyert and March, 1963). For this reason, generalizations can only be of partial validity.

Figure 3.1-1 Urban Goods Transport and Related Decisions

	FIRM LOCATION
LONG-RUN	PLANT SIZE (CAPACITY)
↓	PRODUCTION MIX AND TECHNOLOGIES
	PRODUCTION LEVELS
	PRICING OF OUTPUTS
MEDIUM-RUN	GOODS PURCHASES
↓	DISTRIBUTION LOGISTICS
	INVENTORY MANAGEMENT
	VEHICLE SUPPLY
	CONSIGNMENT FREQUENCY, DESTINATIONS, AND MODES
SHORT-RUN	GOODS VEHICLE TRANSPORT PATTERNS

Plant Location

Long-run choices include those of plant location, plant size, and characteristics. The choice of location is clearly a primary determinant of urban freight transport behavior and activity. The effects of locational choices are both direct, in that they position and affect the intensity of traffic generators, and indirect in that they influence the full range of medium and short-term decisions which are themselves determinants of urban freight transport flows. Classical location theory, of course, accords a major role to freight distribution costs as principal determinant of locational choices. If transport costs have influenced the location of a firm, then we would expect that this effect would be reflected in its patterns of trade and transport (Isard, 1956).

It may be recalled that "the locational decision is not, of course, taken in isolation, but is related to other considerations such as scale of operations, combinations of factors of production and market conditions". (Smith, 1971, p. 96) The choice of location is frequently simultaneous (or at least interdependent) with the choice of plant characteristics, particularly those relating to space inputs such as land area and floor space. As Romanoff (1975) has observed, decisions about space inputs, are in effect, decisions about plant capacity.[3]

Locational decisions may also include long-run logistical decisions concerning the location and scale of warehouses and terminals if these are owned or leased by the firm. Clearly these decisions, which are also influenced by a wide range of production, transport, and related factors, have a substantial impact upon urban goods movement.[4]

Production, Consumption, and Trade

In the medium term (i.e., with its location fixed), the firm makes production and consumption choices and trades with its sources of supply and the consumers of its output. As a producer, the firm exercises choice over, among other factors, the level, mix, and attributes of outputs it produces, the production technologies employed, and the prices set for its products.

A great many changes in spatial activity patterns result not from changes in the location of firms, but from

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[3]This point was also made by Churchill (1967).
[4]Reviews of the operations research literature treating depot location are given by Eilon *et al.* (1971) and Meyburg, Lavery, and Parker (1974).

the adaptation of firms to the economic environment. For many firms, the location question "would appear to be much less one of given the production, where shall the entrepreneur locate than one of given the location, what and how much shall he produce?" (Hamilton, 1974, p. 7).

A partial answer to this question for many firms is the production of multiple and often diverse products. The heterogeneity of production at the level of a single firm or plant would appear to be a primary causal explanation for the non-homogeneity of the commodity composition of urban freight consignments.

The current trend toward specialization, which is another production choice response, also has particular implications for urban commodity flows. Increasing specialization requires an increase in interfirm transactions required to assemble finished products (Wallace, 1971) and thus is likely to increase the frequency and volume of intraurban trade and goods transport.

Other important aspects of competitive producer behavior involve product differentiation and pricing strategies, both of which affect the volume of the firm's sales. Product differentiation may take many forms including variations in product quality, design, packaging, delivery rates, the terms of sale, or customer service (Chamberlain, 1933). The firm's ability to influence equilibrium market prices may stem from its location because, as observed by Richardson (1969, p. 3), "distance itself confers monopolistic protection", or from other factors such as product differentiation which may also lead to the imperfect competition which characterizes urban markets (Chamberlain, 1933).

It is generally accepted that the markets characterized by widespread, but unevenly distributed, patterns of producers and consumers may be best described as oligopolistic (Richardson, op. cit.). This may be of particular importance in understanding the spatial pattern of intraurban trade because of the alternative spatial pricing policies that may accompany spatial oligopoly. The most prevalent alternatives to f.o.b. pricing are thought to be free-delivery, equal-delivered, and base-point pricing strategies. Of these, the first two (which are similar) would seem to be most common in urban areas. Equal-delivered pricing policies discriminate against nearby consumers in favor of more distant recipients of goods and should result in a marked decrease in the importance of transport costs as a determinant of sales.

A final point to be mentioned from the perspective of production provides the link to the discussion of the firm as a consumer of goods. The firm's demand for input commodities is determined by its choice of the level of production and the process (technology) employed to produce its outputs. As stated by Samuelson (1964, p. 526), a major result of the theory of production is "that the demand for each input will depend upon the prices of all inputs, not on its price alone. Cross elasticities between different factors are as important as regular elasticities." This indicates the rather considerable simplification that is involved if the firm's consumption of a commodity is assumed to be independent of its consumption of other commodities.

The level of the firm's demand for inputs is based on planned production, which is a function of the market demand or the expected market demand for its outputs. Because of temporal variation in the demand for the firm's products, there is likely to be variation (typically with a time lag) in the firm's demand for inputs. The actual timing and size of purchases generally will also depend upon the firm's inventories and its inventory policies, as well as production requirements.

The firm's (receiver's) demands for inputs are translated into specific orders for goods from suppliers/shippers. As Terziev (1976, p. 22) has recognized, each order for a particular commodity involves a choice among suppliers and a decision on the amount to be purchased.

A wide variety of factors are thought to influence the choice of suppliers of inputs and thus the origins of freight flows.[5] Among these factors are commodity attributes, cost, and transport level of service characteristics. Each of these will be described briefly.

Commodity attributes expected to play a role in the consumption choices made by the firms are those which influence the firm's judgements of the utility of the product. Durability, perishability, aesthetics, and performance specifications are among the attributes which are likely to be determinants of commodity utility.

A general assumption of many studies of freight flows is that firms in the same (narrowly classified) industry produce outputs which, if not identical, are sufficiently similar to be substitutes as viewed from the perspective of

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[5]Terziev (1976) has reviewed a variety of contemporary intercity models and listed their explanatory variables. Wallace (1971) and Bayliss and Edwards (1970) provide a discussion of other factors.

consumers. This assumption has been squarely challenged by Gilmour (1974, p. 346) who argues persuasively that "a modern industrial society requires an astonishing array of products designed for very specific purposes; the result is ... that any particular one is manufactured by only a small number of firms." Consequently, there may be few alternative suppliers for many goods purchases, thus restricting the "possible variation in the spatial pattern of inter-industrial linkages." (Gilmour, op. cit., p. 347).

Another determinant of the choice among alternative suppliers for goods purchases is price. The price per unit of an input is likely to vary from supplier to supplier and is also likely to vary with the size of the order (Terziev, op. cit.). The total delivered cost of the commodity is probably the predominant cost factor in the firm's decision. Following Terziev, the delivered cost is the sum of the various cost components including the f.o.b. price; ordering and handling costs; packaging costs; loss and damage; and transport costs.

Other relevant costs are the logistics costs which include the opportunity cost of capital, any potential loss of value during transit, and inventory costs. Inventory costs should probably be regarded as including the costs of a stockout which may partially counteract the carrying costs of maintaining inventories (Roberts, 1977).

Transport level of service characteristics are important determinants of some of the cost components noted above and are an important determinant of purchase decisions in their own right. Among the level of service attributes thought to influence goods purchases are schedule frequency or waiting/response time, delivery speed, transit time reliability, and the likelihood of loss and damage (Roberts, 1977).

Obtaining rapid and reliable transport of goods which have been ordered is of direct economic value to the firm (Ashton, 1947). The speed and reliability of goods transport are inversely related to the size of inventories needed to insure adequate supplies for production. Therefore, there is a direct tradeoff between level of service attributes and inventory costs.[6]

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[6]As Wallace (1971) has observed, the importance of these level of service characteristics of speed and reliability are expected to vary from commodity to commodity and among the various stages in the production process from raw material extraction to final goods. The perishability of goods as well as other factors which may cause changes in the economic value of goods through time are expected to be important determinants of the significance of transport level of service attributes.

Although there are clear exceptions and counter-examples, it is generally the case that both consignment transit times and transit time reliability are functions of the length of haul from producer to consumer, holding constant the mode, transport network characteristics and various other factors. Location theory suggests that proximal location and high transport level of service may be of particular importance to small firms or to those who require specialized inputs (Hoover and Vernon, 1962). The level of service of transport is presumably a major factor which makes firms prefer local supply linkages.

Other factors which may also be correlated with distance and which may influence the choice of suppliers include the availability of information (Gilmour, 1974) and the time and cost required to make purchases. These factors are also considered to stimulate the agglomeration of commercial activities (Hoover and Vernon, op. cit.).

Distribution Logistics

The organization of the freight transport methods utilized in moving goods in urban areas is the subject of a variety of higher-level transport and related decisions which firms make in the medium term. The basic logistics framework is the foremost class of these choices.

As shown in the example in Figure 3.1-2, the firm interacts with suppliers and consumers in a logistical system.[7] Logistical system decisions include choices of inventory management strategy, distribution channels, and the supply of transport facilities and services. These decisions of firms may be distinguished from shorter-term freight transport decisions in that the former are not made with respect to individual freight consignments.

The firm's principal transport logistics decisions include the choice of whether or not to be a transport provider, and, for those that decide to produce proprietary road transport for at least some consignments, choices about vehicle fleet size and composition. Proprietary road transport may convey important advantages over for-hire transport in terms of cost and level-of-service provided to the firm or the consumers of its output (Oi and Hurter, 1965). As indicated in Chapter 2, proprietary transport is the principal means of urban freight distribution.

The vehicle fleet size decision for the road transport provider may be conceptualized as the determination of the

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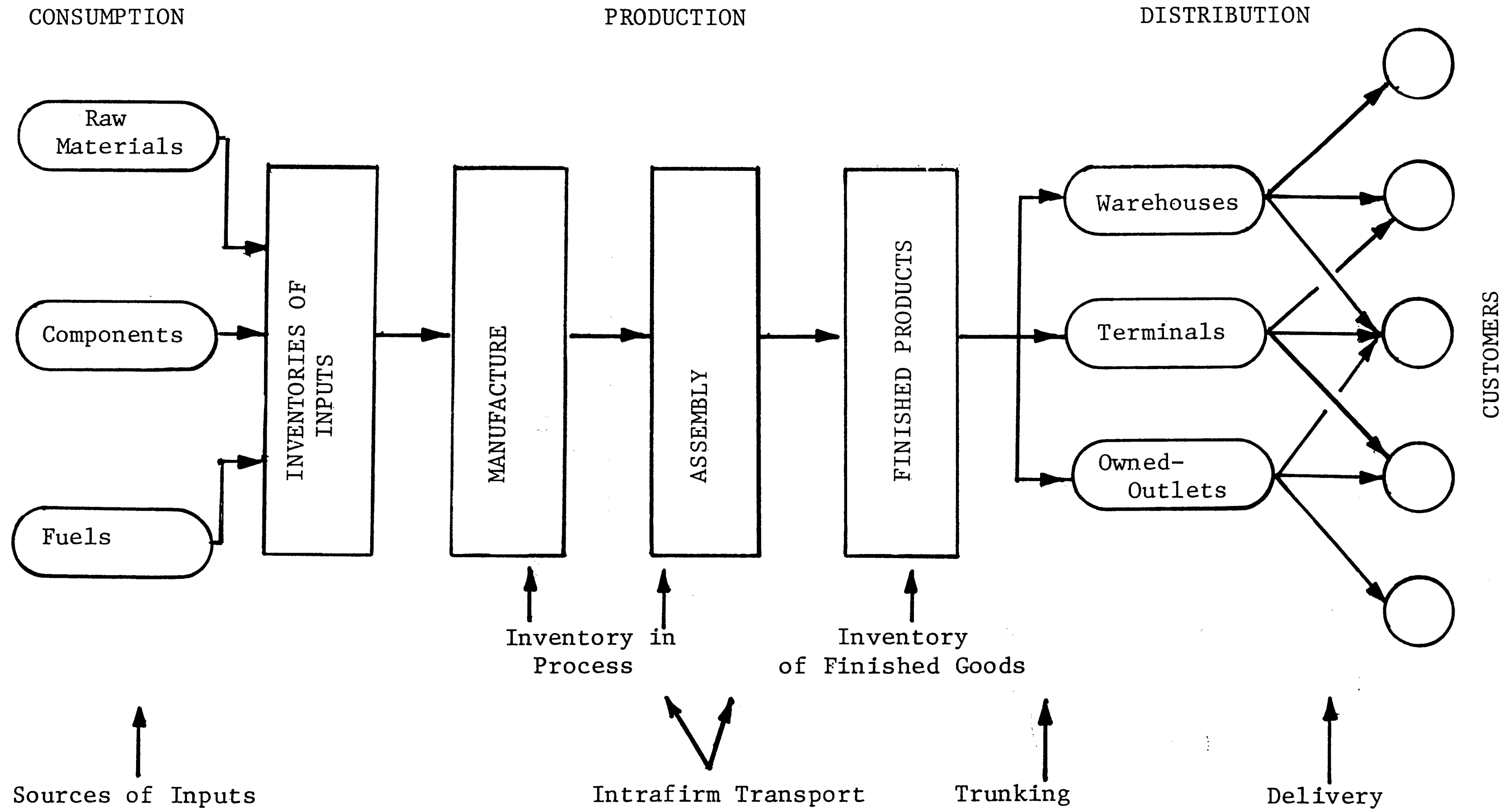
[7] In the example, the direction of the freight flows is from producers or distributors to consumers. This, of course, need not always be the case and activities such as for-hire transport, the postal system, and waste collection may involve patterns of freight flows in the opposite direction.

Figure 3.1-2

A Firm's Logistics System



Source: After Fair and Williams(1975, p. 51) number and type of vehicles to be operated by the firm in the face of fluctuating and uncertain customer demands. This problem is one faced by both the public hauler who transports goods for others and the firm which operates its own fleet although its primary business is not that of providing road haulage.

A firm's objectives in making its fleet size decisions can take a variety of forms. Possible objectives include minimizing the number of vehicles required, minimizing the total cost of operation, or maximizing the utilization of vehicles and drivers (Webb, 1972a). Generally, however, any specific objective is subjugated with respect to the firm's broader aims for its overall distribution system.

Apart from the limited consideration of the fleet size problem in the operational research literature, there has been little attention given to this question, particularly from a behavioral view. At the risk of being unduly speculative, the following discussion will attempt to indicate some of determinants of these decisions.

The firm's choice of the number, types, and capacities of goods vehicles in its fleet is presumably influenced by many factors including the expected volume and size distribution of consignments to be transported, commodity characteristics, level of service objectives, and costs. The number of vehicles operated will tend to be a function of the expected volumes of demand and the capacity of the vehicles to be utilized. An essential point in the tradeoff between the number and size of vehicles and costs would appear to be that not only can larger vehicles transport more shipments, but they can also transport a wider range of shipment sizes (Gould, 1969). Generally speaking, one would expect vehicle capacities to be large relative to average shipment sizes, but this may not always be practical.

Commodity characteristics are also likely to exert an influence upon the dimensions and attributes of the carrier's fleet. In particular, some commodities, such as perishable foodstuffs or liquids, may require specialized transport vehicles. Customary methods of packaging consignments may also lead to preferences for specific vehicle types.

Another factor seemingly overlooked in discussions of the fleet size decision is the relationship between the size and composition of vehicle fleets and the transport level of service afforded the transporter's customers. The larger the carrier's capacity relative to the demands placed upon it, the higher the level of service that can be provided to receivers. If it were not important to serve customer demands expeditiously, the firm would tend to use fewer vehicles, delay shipments done during peak periods, and even out its transport operations. If, on the other hand, a high level of transport service is desired, it is likely that this objective will be reflected in the fleet size decision as a deviation from the minimum cost choice.

Lastly, the costs associated with different fleet size and composition alternatives are expected to be determinants of these choices. Cost considerations may include the tradeoff between initial outlays and maintenance and operating costs, and the tradeoff between costs (both fixed and variable) and vehicle capacity.

Typically, higher costs are associated with larger capacity fleets. However, the functional relationship between both fixed and variable costs and vehicle capacity appears to display decreasing costs per unit of capacity over a nominal range of vehicle sizes.[8] For this reason, and because of the additional flexibility afforded by larger vehicles mentioned previously, the vehicles chosen may have larger capacities than would appear to be needed on the basis of casual observation of fleet capacity utilization.

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[8] See, for example, Eilon et al. (1971)

The fleet size decision is broader and more complex than simply determining the number of vehicles to be owned by the firm. In addition to the relatively infrequent purchases of vehicles, firms may make more frequent adjustments in the size and composition of their vehicle fleets. Because hiring arrangements provide a clear substitute for vehicle ownership (Bayliss and Edwards, 1970), it makes sense for firms to augment their supply of vehicles during periods of high demand even at somewhat higher unit costs.

As Gould (1969, p. 85) observed:

> "The day-to-day and seasonal variation in demand is considerable. It is plainly uneconomic to have sufficient vehicles in the company fleet to meet peak demand, because a number of vehicles would then be idle for most days of the year. Similarly, it would be uneconomic to insist that each vehicle in the company fleet be fully occupied throughout the year, as this would mean excessive hiring costs somewhere between these extremes. Company vehicles will sometimes be idle or delicensed. At other times outside vehicles will have to be hired."

As indicated above, firms may also make downward adjustments in vehicle fleet capacity or simply make changes in the composition of the fleet. Because of transaction costs (the disutility of making changes in the fleet) and the discrete character of the units of supply, some degree of disequilibrium between the firm's demand for and supply of vehicles by type is likely to exist. Another alternative which can be employed in response to unanticipated increases in the demand for transport is the use of for-hire transport for a subset of the firm's consignments that are difficult or costly to serve with vehicles that the firm operates itself.

An important point is that the firm's fleet size decisions are not independent of their short-run decisions about consignments and vehicle routing and scheduling. Rather, firms' experience and satisfaction with these decisions are likely to be major determinants of changes in vehicle fleets.

The preceding discussion should make it clear that these logistical decisions are likely to exert a strong influence upon the short-run transport pattern decisions made by the firm. In particular, decisions about goods shipments and vehicle routing and scheduling fundamentally depend upon the number and capacities of the vehicles available for utilization. As a result, transport pattern decisions made by the firm can be expected to vary systematically with changes in the number and characteristics of the vehicles under the firm's control.[9]

The Transport of Goods Consignments

In the short-run, firms make decisions about the characteristics and transport arrangements for individual or groups of consignments. Although some of these decisions may be largely predetermined by prior, longer-term distribution logistics decisions, it is generally the case that different transport alternatives are available for individual consignments.

The transport of consignments may be thought of as being of two types - trunking and delivery. Trunking,. as Eilon, *et al*. (1971, pp. 1-2), have defined it, refers to

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[9]The mix of privately-owned and hired vehicles may also be a determinant of short-run transport pattern choices. For example, Eilon *et al*. (1971, p. 225) has suggested that "in any given period, the routes that are assigned to the hired vehicles must be carefully considered on the basis of the relative costs of operating company-owned or hired vehicles." In general, this will lead to a tendency for the longer tours in the distribution scheme to be assigned to the firm's own vehicles. Moreover, the differential costs of operating owned and leased vehicles is likely to result in a different set of goods vehicle tours and trips than that which would be chosen if the cost differential did not exist. This occurs because it is more efficient from a total cost point of view to reduce the distance travelled by the leased vehicles even if this results in an increase in the total overall distance traversed by all of the vehicles.

"the shipment of goods to depots [which] is often carried out in bulk, while the supply to customers generally involves small consignments so that trunking and delivery operations need not always use the same transportation media." Although trunking may occur within regional boundaries, it is typically associated with the transport of interregional commodity flows.

The choice of mode or modes for trunking is the classic freight transport mode choice question, which has been discussed extensively in the literature[10] and will not be pursued here. However, it must be pointed out that the choice of mode for trunking is interdependent with other transport choices including the choice of the transport mode for intraregional shipments. As empirical evidence presented in Chapter 2 indicates, however, the predominant mode for intraregional transport is the commerical vehicle often operated by producers or distributors themselves.

The transport needed to move consignments of goods from shippers to receivers may be provided by the receiver, a transport firm or carrier, or by the shipper (on its own account). A short-run logistical choice is that which

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[10]See, for example, Bayliss and Edwards (1970), Roberts and Kresge (1971), Kullman (1973), Chisholm and O'Sullivan (1973), and Watson (1975).

governs whether or not the goods will be collected by or transported to receivers. It is not clear whether this decision is primarily the province of the shipper or receiver, although the one might expect the latter to have the option of goods collection in some cases. In hypothesizing that the ability to control inputs is a determinant of a firm's decision to engage in proprietary road transport, Oi and Hurter (1965) have given at least one reason why some firms might make this choice.

The above explanation notwithstanding, empirical evidence suggests that the principal use of proprietary transport for both interregional and intraregional freight shipments is for the delivery of output rather than the collection of inputs (Wilbur Smith and Associates, 1969; Wallace, 1971; and Ogden, 1977a). In this case, as in the case of for-hire transport, the associated trade and transport decisions are made by different microeconomic entities, respectively.[11] Under these logistical arrangements, decisions about goods consignments and goods vehicle trips are clearly separable from decisions which precede them about goods purchases.

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[11]Except in the special case of intra-firm, inter-establishment transactions.

This conclusion may not apply if own-account transport providers collect their purchases rather than, or in addition to, distributing their outputs.[12] However, even in these situations, transport pattern choices may be separable from and conditional upon decisions about goods purchases for the following two reasons. First, decisions about goods consumption are typically made by different sub-entities within firms than those which make transport decisions. Second, even when this is not the case, decisions about goods consumption may frequently precede decisions about goods vehicle trips. The above arguments, and the fact that goods delivery is very much more common than goods collection, provides the basis for the simplifying assumption needed for theoretical analysis that transport pattern decisions are separable from, although conditional upon, decisions determining patterns of goods purchases and sales.

It should be clear that the context in which decisions about goods consignments and vehicle trips are made is exceedingly complex and that these decisions are not independent of many choices made by a variety of behavioral entities in differing time frames. A principal implication

[12]As is evident from the urban passenger travel demand literature, this is generally the case for most household shopping travel.

of this discussion is that firm location, trade, logistical arrangements, and vehicle supply are factors which should enter an empirical assessment of the determinants of urban goods vehicle traffic.

In the remainder of this chapter we shall concentrate on a theoretical examination of transport pattern choices under the assumption that all the decisions enumerated above are fixed. Further, except as otherwise noted, it will be assumed that the firm distributes its products locally, provides all its local transport, and that its supply of vehicles is fixed.

3.2 Short-Run Urban Freight Transport Decisions

The firm's short-run transport pattern decision encompasses the full set of transport choices made in serving its customers' demands in a relevant time period. The alternatives for these choices, for even simple problems with few customers and vehicles, are combinatorially explosive in number and present the firm with a complex decision problem. In order to understand the determinants of urban goods vehicle traffic, it is necessary to understand the nature of the firm's transport pattern choices and the factors that determine them.

The organization of the discussion is as follows. In section 3.2.1, the transport pattern choice problem is defined and the procedures employed by firms in making these decisions are briefly described. This is followed by a highly simplified numerical example which illustrates some of the important characteristics of these problems. A conceptual description of the factors that determine transport decisions is offered in 3.2.2.

3.2.1 The Transport Pattern Decision

The firm's transport pattern decision is defined as the choice of the set of consignments to be transported within a given time period and the selection of the corresponding set and sequence of goods vehicle trips with which this is to be accomplished. Following Adler (1976), who employed similar terminology for passenger travel, the designation "transport pattern" is intended to reflect the fact that urban freight transport decisions are made about groups of consignments and groups of goods vehicle trips.

Providers of urban freight transport make transport pattern decisions at frequent intervals. Typically, there is a relationship between the frequency of decisionmaking and the duration of goods vehicle trip patterns. As Webb, (1972a, p. 183) has suggested, "journeys are rarely planned for a vehicle more frequently than it completes journeys." The frequency and duration of the transport pattern choice are most often based on the need to organize the daily work cycle or a work shift within a daily pattern. This would appear to be the main reason that daily transport pattern choices are common in urban freight distribution (Webb, op. cit.).

Transport pattern decisions for pure delivery problems are conditional upon customer demands for the firm's products. These demands accumulate at some rate (which may vary) through time. At any given point in time, the firm typically has a list of specific orders and shipment sizes requested by each of its customers. Associated with some or all of the demands may be statements of consumer preferences with respect to the timing of goods delivery.

The firm responds to these demands by selecting the consignments to be transported to customers within a journey planning cycle. It is important to recognize that because of either its own objectives or because of constraints on the supply of goods or goods transport, the firm's selection of consignments or consignment characteristics may deviate considerably from its customers' stated desires. For example, if the supplier is out of stock or if some products are in short supply, there may be some substitution or omission of the products ordered. Alternatively, the firm may make multiple shipments of smaller amounts at different points in time rather than a single shipment of the total amount ordered. Limitations of transport capacity or cost will often make it difficult to satisfy all customer desires for timely and reliable deliveries. Consequently, the firm may need to delay or accelerate deliveries and/or deviate in other ways from customers' preferences for the timing of goods delivery.

Various procedures or strategies are employed by firms to structure decisions about which shipments should be selected for delivery within a journey planning cycle for its vehicle fleet. One possible procedure is that in which the firm makes deliveries in the sequence in which the customer orders are received. If a customer requests delivery at a later date, rather than immediately or as soon as possible, this shipment will be inserted in the sequence at roughly the appropriate time. A second alternative involves the grouping of deliveries by geographic location. Under this strategy, deliveries are made to different customer locations on a regular schedule, perhaps on the same day of the week.[13]

Probably the most common situation is that neither of the above procedures is followed rigidly. Rather, "when the time cycle for satisfying orders is greater than the journey time cycle..., then orders may be given different priorities for fulfillment" (Webb, 1972a, p. 191). Various factors which may influence the assessment of delivery priorities will be discussed in the next part of this chapter.

Selecting and scheduling the consignments to be transported by the vehicle fleet generally requires estimating the time needed to perform each required task. Clearly, this decision is a significant determinant of transport efficiency. Moreover, the penalty for scheduling more deliveries than can be performed can be severe in terms of added cost or dissatisfied customers. To the extent that there is a principal "method" for scheduling the number of

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[13]Both of these strategies may have some level-of-service implications. The first procedure should tend to minimize the time interval which elapses between customers' orders and the receipt of the deliveries. The grouping of customer deliveries by geographic area and with a regular service rotation may (absent capacity constraints) place an upper bound on the maximum waiting time for deliveries. Both of these strategies are simple to apply as they require no discrimination among the attributes of alternative shipment patterns, and this may be an important reason why they are used.

deliveries for each vehicle, it appears that the "method" is experienced, subjective judgement (Webb, 1972a).

The duration of a journey plan is fundamentally determined by the routes planned for the vehicles in the delivery fleet. Consequently, decisions about the shipments to be made with a daily transport pattern are likely to be strongly interdependent with vehicle routing and scheduling decisions, the other integral component of the firm's transport pattern choice.

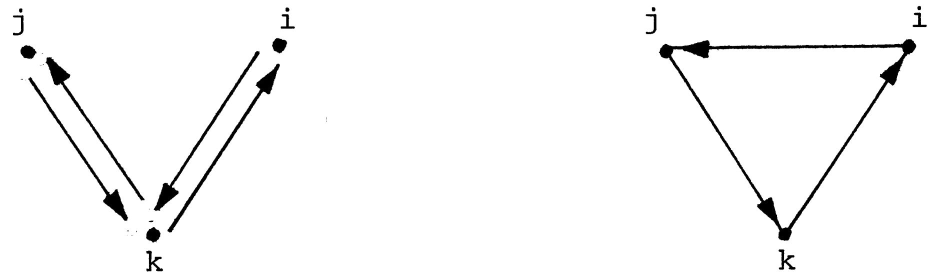
Vehicle routing and scheduling entails the allocation of each delivery to a vehicle and the determination of the sequence of deliveries and thus the trips and tours to be made by each vehicle in the fleet. Although the objectives for transport pattern choices may be complex, a primary goal in the allocation of deliveries to vehicles and in the routing of vehicles is certainly to lessen delivery costs by reducing the distance and travel time required to deliver the chosen set of shipments. A principal way in which this is done is through the selection of goods vehicle trip patterns which are characterized by a high degree of trip chaining (i.e., a large number of trips and deliveries per vehicle tour).

Note that the longest transport pattern in terms of the distance traversed is the one in which a separate round trip is used to make each delivery. If instead, deliveries are made on multiple-delivery tours, a considerable reduction in the distance to be travelled by the vehicle fleet can be achieved. This point is illustrated in Figure 3.2-1 which shows the savings SAV_{ij}^{k} which result from making two deliveries i and j on the same tour originating at the depot k rather than by making each on a separate tour. The expression for SAV_{ij}^{k} in terms of the internodal distances is often referred to as the savings function.

An extension of the above reasoning suggests that the reductions that can be achieved in the distance to be travelled by a vehicle fleet will be a function of the degree of trip chaining in terms of the number of deliveries and trips per tour (Eilon, et al., 1971). Consequently, a high degree of trip chaining is hypothesized to be a principal characteristic of urban goods vehicle trip patterns even if distance/travel time minimization is not the sole objective in determining the trips to be made in delivering a set of consignments.

When the set of consignments to be transported is fixed, the transport pattern choice problem reduces to the classical vehicle routing and scheduling problem described

Figure 3.2-1 The Savings Function



Before linking After linking

$$SAV_{ij}^{k} = (2d_{k,j} + 2d_{k,i}) - (d_{k,i} + d_{i,j} + d_{j,k})$$

$$= d_{k,j} + d_{k,i} - d_{i,j}$$

in the operations research literature and defined in Chapter 2. Recall that the vehicle routing and scheduling problem has the objective of finding the shortest path, subject to a variety of constraints, for a given vehicle fleet to deliver a fixed set of consignments of known characteristics (and destinations) from a central depot. Relevant constraints may include restrictions of vehicle capacity, tour and transport pattern duration, and deadlines for customer deliveries.

The vehicle routing and scheduling problem belongs to the class of hard combinatorial problems. These problems are often simple to pose and clearly have at least one optimal solution. However, they are extremely difficult to solve even with massive computing power because of the vast number of possible solutions. In fact, it is generally impossible to obtain optimal solutions to problems of even modest size (Golden et al., 1975). Consequently, a wide variety of heuristic techniques have been developed for obtaining computer solutions to vehicle routing and scheduling problems.[14] The most successful methods are generally considered to be "sequential" methods in which "at each step one set of tours is exchanged for a better set of

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[14] Extensive reviews of procedures for solving vehicle routing and scheduling problems are to be found in Gaskell (1967), Webb (1972b), Eilon et al. (1971), and Golden et al. (1975).

tours" (Golden. *op. cit.*, p. 12). The improved tours are found by connecting deliveries "according to some criterion or measure of priority, subject to the problem restrictions" (Webb, 1972b,p. 363). Many of these procedures follow Clarke and Wright (1964) in employing variants of the savings function as a criterion for forming trip links.

Since very few vehicle routing and scheduling decisions that are made in metropolitan areas make use of computer procedures, it is relevant to consider the manner in which the preponderance of these decisions are actually made. However, many manual methods defy description in that they follow no set procedures. Consequently, it is possible to comment only on manual methods which have some tangible manifestation.

One of these methods of vehicle routing might be called the visual approach because the trips are chosen by making a "visual inspection of customer locations on a map" (Gaskell, 1967, p. 281). Although the decision process is obviously covert, there are rules of thumb which may be discerned. For example, Gaskell (*op. cit.*, p. 282) provides the following observations.

> "Most planners would agree to start with customers at extreme points in the area to avoid long journeys to single customers, and to minimize added mileage as each customer is allocated.

Simultaneous assessment of a number of routes is also a feature."

Interestingly, when sufficient time is available, the visual method may outperform computer methods (Gaskell, _op. cit._).

Another common approach for allocating shipments to vehicles is the pigeon-holing method (Webb, 1972a). To employ this method, dispatchers sort delivery notes into pigeon-holes associated with specific geographic areas. Typically, orders which are larger than vehicle capacities are represented by multiple delivery notes. To the extent possible, the destinations for a single route are drawn from a single pigeon-hole. Then destinations are added from adjacent geographic areas until the capacity of the vehicle is reached or an acceptable threshold load factor is obtained. Other deliveries which have not been allocated to a tour may then be allocated as appropriate.

Since the pigeon-holing method does not specify the arrangement of trips for each tour, a further procedure is needed for a complete specification of a method of journey planning. One such procedure, which may correspond to actual behavior, is the proximity rule described by Webb (1972a). Under the proximity rule, links are formed by joining the closest nodes except insofar as this is precluded by the restriction that no node is connected to more than two other nodes (including the depot) and that there are no internal circuits.

When these manual methods of journey planning are employed, the routes obtained are typically examined for further improvements which can be made. Consequently, even the manual methods that can be described do not necessarily lead to deterministic and replicable vehicle routings.

The complexity of these decisions may be appreciated by considering a concrete example of a transport pattern choice problem. The example to be presented is also helpful in illustrating some of the important aspects of these decisions.

3.2.2 An Example of a Freight Transport Choice Problem

A simplified example of a freight transport pattern choice problem is depicted in Figure 3.2-2 which shows the locations of the delivery depot, D; four customers, i, j, k, and l; and their distances from one another. It is assumed that deliveries, the amounts of which are indicated in Table 3.2-1, are to be made with a single vehicle with a capacity of 100 units. Because the vehicle capacity is less than the total amount of the customer demands, at least two tours will be required to perform the requisite distribution.

Figure 3.2-2

A Transport Pattern Choice Problem

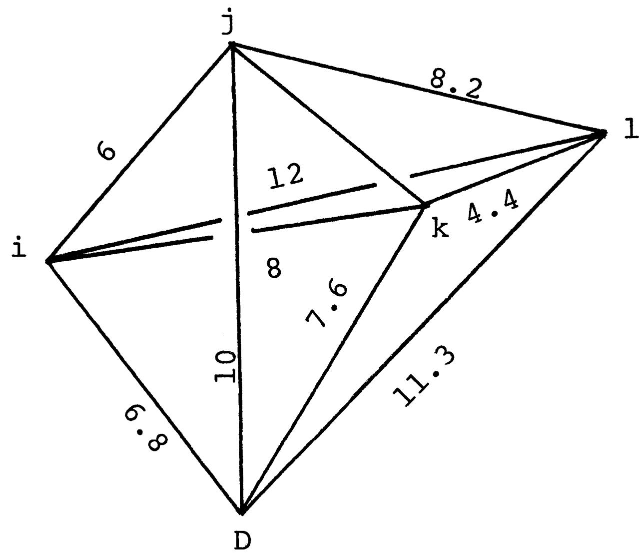

Table 3.2-1 Customer Demands

Customer	Shipment Size
i	30
j	25
k	20
l	50

The example is highly simplified in that the shipment pattern is predetermined. Further simplifications are that the distances between customers are known, distance minimization is assumed to be the sole objective to be sought in routing the vehicles, and capacity is the only relevant constraint. Importantly, even for this simple distribution problem, the minimum distance transport pattern is not immediately clear. Rather, some inspection and/or calculation is required to evaluate the alternatives.

Figure 3.2-3 shows six feasible alternative transport patterns for making the deliveries from the depot to locations i, j, k, and l. The differences among these alternatives illustrate some transport pattern characteristics that vary considerably with the outcomes of vehicle routing decisions. The most obvious differences among the alternatives are in the number of tours and trips, their origin and destination patterns, and in related characteristics. Specifically, the alternatives vary in terms of the total distance traversed, the average trip and tour lengths, the number of depot (home)-based trips, and the distribution of multitrip tours. It should be emphasized that the alternatives are very different in terms of trip generation and distribution.

Figure 3.2-3

Some Alternative Transport Patterns

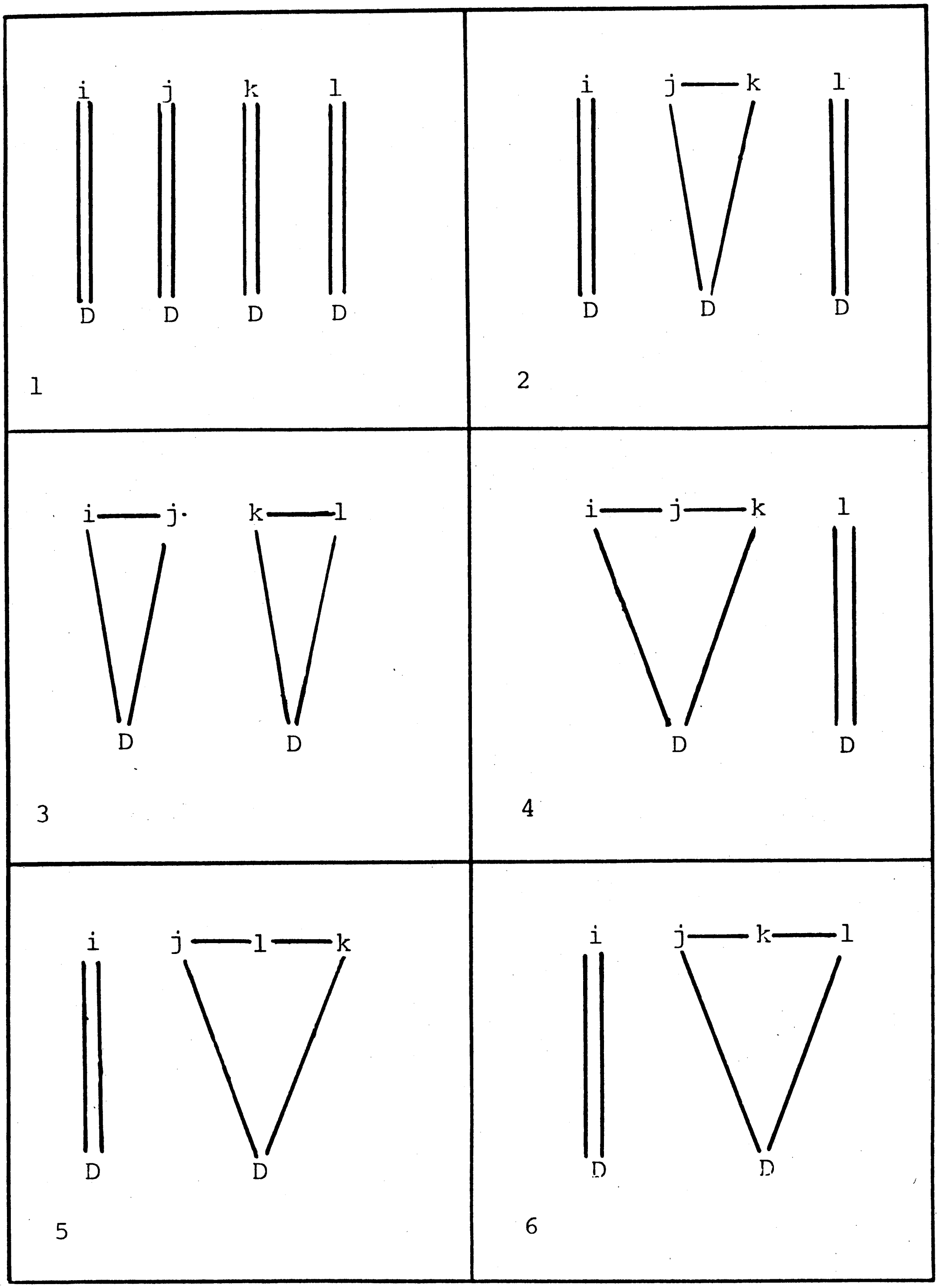

Table 3.2-2 summarizes the number of tours, trips, trips/tour, and the total distance for each of the alternative transport patterns. Significant variation in each of these attributes is in evidence. If the goal is the minimization of the distance travelled, alternative 5 is the preferable selection. Alternative 5, however, is only one of several alternatives with the highest average number of trips per tour or the minimum number of trips and tours.

Another point to note about the example is the importance of the constraint of vehicle capacity as a determinant of the optimal trip pattern. If, for example, all four deliveries could be made on one tour, the vehicle would have to travel only 33 units to traverse the trip sequence, D-i-j-l-k-D. In this particular example, it is the constraint which determines whether or not deliveries i and j are connected by a goods vehicle trip.

A disquieting aspect of transport pattern choices which may be inferred from this simple example is that small changes in the characteristics of journey planning problems may have large effects upon the chosen solutions and upon patterns of goods vehicle trips. Moreover, these effects may be very difficult to anticipate.

Table 3.2-3

Transport Pattern Characteristics

Travel Pattern Alternative	# Tours	# Trips	# Trips/ # Tours	Total Distance
1	4	8	2.0	71.4
2	3	7	2.3	58.9
3	2	6	3.0	46.1
4	2	6	3.0	48.1
5	2	6	3.0	43.8
6	2	6	3.0	44.4

Consider the consequences, for example, of a doubling of each of the customer demands. This would render all of the alternatives shown in Figure 3.2-3 infeasible except for the first two alternatives. If on the other hand, the size of demand i is tripled, it has no effect on the chosen trip pattern. Thus, not all changes in the demand for goods will necessarily require changes in trip generation and distribution. These variable responses would appear to add considerably to the complexity of analyzing the determinants and outcomes of transport pattern choices.

The preceding discussion has illustrated a variety of ways in which decisions about aspects of transport patterns such as individual trip links are likely to be highly interdependent with decisions about other aspects of these choices. These observations stand in contrast to the contrary assumptions embodied in existing models of goods vehicle trips and provide the motivation for a more holistic theory of the factors that determine transport pattern choices.

3.2.3 Factors Influencing Transport Pattern Decisions

This section presents a conceptual description of the firm's transport pattern decisions. These decisions are discussed in terms of the firm's preferences for attributes of transport pattern alternatives, the alternatives available, and the choice process employed. This conceptual framework also provides an organizational structure for a discussion of the factors that influence transport pattern choices.

At least four classes of attributes are hypothesized to influence the firm's assessment of alternative transport patterns. For the purpose of analysis it may be useful to think of the firm's preferences for these attributes, and thus for specific transport pattern choices, in terms of a utility function such as the one below:

$$U(\text{transport pattern}) = f(S, C, LOS, FC) \tag{3.1}$$

Where S = the attributes of the set of shipments contained in the transport pattern

C = the cost of the transport pattern

LOS = the non-cost, level-of-service attributes of the trip pattern

FC = the characteristics of the firm

If it is further assumed that the components of the utility function are additively separable and that the relevant firm characteristics are invariant, then (3.1) can be rewritten as (3.2) below:

$$U(\text{transport pattern}) = f_1(S) + f_2(C) + f_3(LOS) \qquad (3.2)$$

Each of these components of the utility of transport pattern alternatives will be discussed in turn.

Attributes of Shipments

When transport pattern choices are made in a context in which the set of customer demands is (or may be) larger than that which can be served in the utility-maximizing choice, the question of the firm's valuation of alternative sets of goods shipments naturally arises.[15] Since the transport of each consignment consummates a contract with possibly unique terms between seller and buyer, it is theoretically possible that the firm could attach a unique weight or priority to the inclusion of the amount of each commodity within the chosen transport pattern. The utility of the shipment set, f_1, may be written as equation 3.3 below.

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[15]In the event that it is feasible to serve all its customer demands in a utility-maximizing transport pattern choice, the choice of the consignments to be transported is trivial.

$$f_1(S) = \Sigma\Sigma a_i^j v_i^j \tag{3.3}$$

where the weights a_i^j are such that $a_i^j v_i^j$ is the utility derived from transporting the amount, v_i^j, of product j to customer i.

The generality of this formulation should not preclude consideration of some more explicit specifications for f_1 which may correspond to the objectives sought by different firms. For example, of all the non-uniform utility weights, one set that may have behavioral content for pure delivery problems are the profits per unit amount of product sales. In addition, if the firm charges a specified fee for goods delivery, this should probably be considered a separate component of f_1 which obviously yields utility.

Frequently, a firm may choose to collect some goods rather than have them transported by another entity. Under mixed logistical systems, there may be a tendency to discriminate between the utility of consignments of goods delivered and those collected. In this case, the firm also saves the transport costs it would otherwise be required to pay. The savings that result are a source of utility which may partially counterbalance or exceed the costs expended.

In a less complex valuation scheme than those described above, the utility of a set of shipments could be represented as a simple function of the total amount (volume or weight) of goods, $V = \Sigma\Sigma v_i^j$, (aggregating over different commodities) or the total number of consignments, N. Often there may be substantial correlation between V and N across transport pattern alternatives. If all of the firm's consignments were of equal size, maximizing the number of consignments or the total volume of consignments would obviously lead to the same choice. If consignments differ considerably in size, however, efficiency in distribution is likely to be more closely associated with the amount of goods transported. The fact that there is significant variation in the size and composition of the consignments transported by firms suggests, as indicated in equation 3.4, that the volume of goods shipped is likely to be the most appropriate single attribute of shipment patterns considered.

$$f_1(S) = \alpha_1 V \qquad (3.4)$$

This simple valuation scheme involves only minimal discrimination among consignment characteristics, and this is one reason why it may be used.

The Costs of Transport Pattern Alternatives

A second major factor in the evaluation transport pattern choices is hypothesized to be transport costs. Since we assume that vehicle availablity is given, we shall disregard the fixed costs of vehicle ownership or lease and concentrate on those that vary with the characteristics of transport patterns. These variable costs are hypothesized to vary as a function of the temporal duration of transport patterns and the distance travelled.

The total length in terms of distance of a given transport pattern is the sum of the lengths of the trips it contains. Each consignment, i, is delivered on a trip of length d_i in a tour which typically (for pure delivery tours) contains an additional trip which is the return trip to the depot. If there are M tours in the pattern and the length of the return trip on tour q is d_q, then the total distance for the transport pattern, d, can be expressed as (3.5) below.

$$d = \sum_{1}^{N} d_i + \sum_{1}^{M} d_q \qquad (3.5)$$

The distance travelled in alternative transport patterns will vary considerably because the length of each trip will vary with alternative sequences of deliveries. The number of trips will also vary with the number of tours.

The distance travelled is dependent upon the locations of the customers to be served and, for the purposes of analysis, it would be desirable to express d as a function of the distances from the firm to its customers. However, unlike simple transport patterns consisting solely of round trips to single destinations, the length of a complex transport pattern composed of multi-destination tours cannot be represented as twice the sum of the distances to each customer summed over all the customers. In fact, one of the most profound effects of the vehicle routing and scheduling behavior typical of the urban freight transport decision process appears to be the reduction of the distance, time, and costs of urban pickup and delivery patterns. Estimating the distance travelled in transport patterns requires an analysis of the length of the tours that result from vehicle routing and scheduling decisions. An analysis of the distance travelled in transport patterns is presented in the next part of this chapter.

The estimated duration, T, of an urban goods transport pattern is the sum of estimates of the total time the vehicles will spend in transit, tt; the time to be spent loading and unloading the vehicles for each consignment,

lt_i; the time to be spent parking the goods vehicle, pt_i; and the time required to obtain a receipt or payment or perform other tasks required to complete the delivery transaction, rt_i.

$$T = tt + \sum_{1}^{N} (lt_i + pt_i + rt_i) \tag{3.6}$$

The transit time is a function of the trip distances and the average speed that goods vehicles can achieve, sp_k, for each trip link k, which is largely determined by network characteristics. Thus,

$$tt = \sum_{1}^{N}(d_i/sp_i) + \sum_{1}^{M}(d_q/sp_q) \tag{3.7}$$

The unloading/loading time is likely to be a function of the volume of each consignment.[16] Therefore,

$$lt_i = L\sum_{j} v_i^j \tag{3.8}$$

where L is the average amount of unloading/loading time per unit of consignment volume. Although on theoretical grounds, parking time and transaction time may vary with location or by time of day, the total duration of these

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[16]Support for the point that the duration of a vehicle stop is a function of the volume/weight of the goods that are delivered or collected is provided by Ahrens et al. (1977).

activities in a transport pattern is likely to be a function of the total number of consignments. Thus, we can write:

$$pt = \sum_{1}^{N} pt_i = N\overline{pt} \tag{3.9}$$

and

$$rt = \sum_{1}^{N} rt_i = N\overline{rt} \tag{3.10}$$

where pt and rt are the total parking and transaction times, respectively, and $\overline{pt}$ and $\overline{rt}$ are the means of these variables. Substituting the above relationships, equation (3.11) below is obtained for T.

$$T = \sum_{1}^{N}(d_i/sp_i) + \sum_{1}^{M}(d_q/sp_q) + LV + N\ (\overline{pt} + \overline{rt}) \tag{3.11}$$

The aforementioned relationships, notwithstanding, journey planners apparently experience great difficulty in estimating the distance and duration of transport patterns (Webb, 1972a). Difficulties in estimating the distances between customers may result from inadequate knowledge of the precise customer locations, the road network, and alternative network path choices, or perhaps the deviation of actual distances from straight line estimates. Estimating the duration of goods vehicle trips is considerably harder and subject to greater error because of the inherent variability of the tasks which must be performed in order to distribute goods.

For example, the driving time for journeys of known distance is highly variable in urban areas (Herman and Lam, 1974). Similarly, estimating the duration of the non-driving tasks is also often very difficult as indicated by Webb (1972a, p. 269) below.

> "Deliveries, for example, are often dependent upon the presence of someone authorized to accept the delivery, and upon access to unloading facilities, and as it is often necessary to wait until these are available, the waiting time may be variable, unpredictable, and completely unaffected by the exertion of effort by the driver."

The difficulty in estimating the duration of delivery tasks may have explicit and tangible behavioral consequences. When a reliable delivery schedule is of particular importance, it is rational for firms to allocate extra amounts of time for performing these activities. This extra time, which has been called "planned idle time" by Webb (op. cit.), is that in excess of the expected mean time required for the delivery tasks. As suggested by Webb, it is clear that this strategy will sometimes result in idle time during which no work will be required of the driver.

The amount of planned idle time will depend upon the perceived variability of the planned activities, the importance placed on the reliability component of the transport level of service provided customers, and the rate of service failure that is acceptable. Risk aversive behavior would suggest as Webb (1972a, p. 214) has noted, that it is not sufficient to estimate the mean expected duration; it is also necessary to estimate the maximum reasonable duration for that particular task. As a result, the values imputed for the sp_i, sp_q, L, $\overline{pt}$, and $\overline{rt}$, are likely to be greater than the mean values specified. For this reason, these variables should be thought of as including the planned idle time associated with each. Alternatively, different measures of the distributions of these variables might be appropriate.[17]

The principal costs associated with the temporal duration of urban freight transport patterns are labor costs which can be expressed as a function of the wage rate for each component activity multiplied by the (person) time involved. If it is assumed that the driver performs all of the requisite tasks, then these costs are equal to WT, where W is the driver's wage rate.[18]

Distance-related costs are the vehicle operating expenses associated with fuel, maintenance, depreciation, insurance and related items. These are likely to vary with

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[17]For a discussion of alternative measures of service reliability see Abkowitz et al. (1978).
[18]If other labor is involved, it should obviously be reflected in the computation of costs.

the vehicle type as well as mileage (Winfrey, 1969), but this variation will be ignored here for simplicity. Therefore, the total operating costs which vary as a function of distance can be represented as the product of the operating costs per unit distance, OC, and the distance as indicated below.

$$OC \cdot d = OC \left[\sum_{1}^{N} d_i + \sum_{1}^{M} d_q \right] \tag{3.12}$$

The total cost, C, is

$$C = W \cdot T + OC \cdot d \tag{3.13}$$

Since cost conveys disutility, the cost component of the utility function, f_2, has a negative sign and can be written, substituting terms as follows.

$$f_2(C) = -\alpha_2 \; W\left[\sum_{1}^{N} (d_i / sp_i) + \sum_{1}^{M} (d_q / sp_q) + LV + N(\overline{pt} + \overline{rt}) \right]$$

$$-\alpha_2 OC\left[\sum_{1}^{N} d_i + \sum_{1}^{M} d_q \right] \tag{3.14}$$

__Transport Level of Service__

The third component of the firm's utility function is hypothesized to be the level of service associated with transport pattern alternatives. The level of service provided to customers may have a variety of important and possibly diverse consequences to the shipper/carriers. At one extreme, there may be severe penalties for failure to provide timely deliveries; this may result in the loss of sales. Alternatively, and for lesser infractions, as Webb (1972a, p. 213) has noted, "service failure results in complaints and often in the need for expensive or troublesome remedial or pacifying actions".

In contrast, higher levels of service are likely to be a source of utility rather than disutility. Assuming that the firm is engaged in a pure delivery operation, the utility it derives is indirect in that the benefits typically accrue in the form of continued or subsequent sales. If the firm performs goods collection, the benefits are also primarily economic and may take a variety of forms including decreased inventory costs or increased productivity of resources.

One dimension of level of service relates to the correspondence between the products and shipment amounts ordered and those delivered. However, we shall assume that this is not a factor in the comparison of transport pattern alternatives and focus solely on transport level of service attributes in the following discussion.

Although the firm's valuation of level of service attributes is expected to differ from that of its customers, it seems likely that the level-of-service characteristics important in the consumer's purchase decisions (discussed in section 3.1) are likely to be important to the transport provider. Consequently, it is hypothesized that the utility associated with transport level of service is a function of the delivery time, DT_i, and the delivery time reliability, RDT_i, for each consignment i.

$$f_3(LOS) = -\alpha_3^1 \sum_1^N DT_i + \alpha_3^2 \sum_1^N RDT_i \qquad (3.15)$$

In the most general case, the firm's valuation of level of service attributes amy differ for each consignment because of the varying desires and requirements of customers and differences in the importance the firm attaches to serving different customers. However, for simplicity, it has been assumed in the above equation that the coefficients of the level of service attributes are the same for all consignments.

Delivery time as used here is the interval of time which elapses between the placing of an order and its delivery. As Webb (1972a, p.184) has stated, "the time between the order being placed and its performance is usually one of the factors which is fundamental to customer assessment of the service being provided". Delivery time should be distinguished from transit time which is the elapsed time from the vehicle's departure from the depot to its arrival at the delivery location. Delivery time will be of greatest importance for orders which are specified in terms of requests for immediate or rapid deliveries. Many orders for goods are made well in advance of desired delivery deadlines; for these shipments, rapid delivery times are likely to be of lesser consequence.

Often it will be impossible for the transport provider to include some consignments in its choice of those to be transported on a given day. In these situations, each consignment may be thought of as occupying a position in a queue, the length of which is likely to be a principal determinant of the delivery time. Note that the component of delivery time attributable to the length of the delivery queue is likely to be of larger magnitude than the components of delivery time attributable to the distance separating producers and consumers within urban areas or the sequence of deliveries in vehicle trip patterns.

Delivery time reliability is the other level of service attribute likely to be of consequence in the evaluation of patterns. Customers frequently articulate specific transport level of service requirements for consignments; in these cases, as well as in the situation in which delivery is promised under certain conditions (as on a schedule),[19] the deviations of the expected performance of the delivery from these requirements or expectations are likely to be the most important attributes of service reliability.

Delivery time reliability may be difficult to estimate and to achieve. If a premium is placed on this attribute of goods transport, firms may make consignment deliveries more reliable (trading off cost with reliability) by building in slack time (or planned idle time) into journey plans as was discussed previously. Another strategy which may be employed in actual practice is for the firm to treat level of service requirements as constraints upon the alternatives considered. If this is done, level of service may not enter the firm's evaluation of alternatives because all alternatives will be satisfactory in terms of level of service.

An interesting and important issue is the effect of trip chaining upon the level of service provided for different consignments. Although trip chaining results in

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[19]Negotiations between shipper and receiver may result in some agreement with respect to the transport level of service terms of delivery. It would not seem unreasonable to expect that firms will attach greater importance to fulfilling such agreements or promises.

the interdependence of the speed and reliability of individual deliveries, its effect is not necessarily clearcut.

On the one hand, it might be argued that trip chaining forces a compromise in level of service for individual deliveries which is traded off against cost savings. This point was argued by Adler (1976) for passenger travel when he suggested that travellers would maximize utility (in the narrow sense of the single attribute of schedule convenience) if each destination were reached on a tour comprised solely of a trip from the base to the destination and a return trip.

On the other hand, trip chaining fundamentally increases the effective capacity of the vehicle fleet and makes it possible for the firm to provide a higher level of service in terms of delivery speed and reliability to many of customers. In fact, the choice of transport pattern alternatives in which only one or few customers are served per tour (with fixed resources) would be likely to result in considerable delays in deliveries and an increase in reliability problems. Assessing the net effect of trip chaining on transport level of service requires making a judgement about which is likely to be the stronger effect or otherwise reconciling these conflicting points of view.

The argument that under optimal conditions each delivery would be made separately depends upon the assumption that there are not substantial overlaps in the desired timing of each. Otherwise, it would not be feasible to perform the deliveries separately. In contrast, we suggest that, more often than not, there will be a substantial overlap in customers' level of service requirements for goods deliveries. Since trip chaining reduces the time required to serve each customer, it would appear to make it easier to accomodate the customers' desires for timely deliveries. Consequently, it is likely that the overall effect of trip chaining is to enhance transport level of service. However, the effect of trip chaining may vary with specific patterns of demand.

Firm Characteristics

Firm characteristics may also influence the preferences of a firm through time and may account for cross-sectional variation in firms' preferences for transport pattern alternatives. Although the effects of firm characteristics will not be discussed in depth, they are mentioned for conceptual completeness and also because they may be of consequence in analyzing empirical data. Some of these factors have already been identified (e.g., plant location, pricing policies, trade relationships, and logistics) and were assumed given for the purposes of this discussion. Particularly important characteristics would appear to be the resources available for providing urban freight transport such as the supply of goods vehicles and logistical arrangements governing the mix of delivery and/or collection activities. Dynamical factors such as levels of output, employment, and inventories may also be of consequence.

In addition to the firm's intrinsic characteristics, the firm's market position may also influence its preferences. In the case of a monopolist, for example, economic theory would suggest that there will be a tendency to attach less weight to the quality or level of the transport service provided to customers.[20] In the opposite situation of a market characterized by a large number of producers or a small number of buyers, the transport level of service provided may be a means of competing with other suppliers.

Another source of variation in the firm's preferences is the vehicle routing and scheduling procedure employed.

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[20]A general analysis of quality choice which supports this view is given by Leland (1977).

Clearly, different decision rules could lead to variations in the preferences for transport pattern alternatives.

<u>An Hypothesis Concerning Transport Pattern Utilities</u>

Holding the characteristics of the firm constant, and combining equations (3.4), (3.14), and (3.15) yields the composite utility function indicated below.

$$U(\text{transport pattern}) = \alpha_1 V - \alpha_2 W[\sum_1^N (d_i/sp_i) + \sum_1^M (d_q/sp_q) + LV + N(\overline{pt} + \overline{rt})]$$

$$-\alpha_2 OC[\sum_1^N d_i + \sum_1^M d_q] - \alpha_3^1 \sum_1^N DT_i + \alpha_3^2 \sum_1^N RDT_i \qquad (3.16)$$

Formally, it would be desirable to derive the first order conditions giving the maximum of U subject to the relevant constraints. However, this problem is mathematically intractable for several reasons, not the least of which are the indeterminateness and discrete character of the choice set. In addition, a variety of complex constraints to be discussed subsequently influence feasible transport pattern choices. These constraints, including the integer character and non-negativity of the variables of choice, pose further obstacles to closed-form mathematical analysis.

Although caution is also warranted in interpreting the function above for several other reasons including its *ad hoc* structure, the absence of empirical parameter estimates, and the problem of instrumental variables, one major hypothesis about the firm's objectives is suggested. This hypothesis is that, *ceteris paribus*, distance (or time) minimizing trip chaining (vehicle routing) increases the utility of transport pattern choices because it tends to increase the utility or decrease the disutility of all the components of the firm's utility function.

Clearly, holding the shipment set and all other factors constant, minimum distance/travel time transport patterns minimize transport costs.[21] Minimizing the distance travelled to serve customers through trip chaining should also increase the number or volume of consignments that can be transported in a given unit of time with fixed resources by reducing the average distance to be travelled in making

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[21]Moreover, firms may typically forego the comparison of alternatives on the basis of cost. Note that the reason that firms estimate the length and duration of a transport pattern is not generally because of a desire to appraise the costs for a given journey plan. Estimates of time and/or distance are typically made because of their use in devising journey plans which are "efficient" in other respects. In particular, these estimates are required to determine the feasibility of transport pattern alternatives in terms of the constraints on their total duration (and possibly level of service) and to evaluate and improve alternatives in terms of the shipments included and the level of service to be provided to customers.

each delivery. Finally, as discussed previously, although the effects are less clearcut, trip chaining is expected to result in more rapid and reliable deliveries. These points suggest that the emphasis in the operations research literature on minimizing the total distance of transport patterns taken may be justified on behavioral grounds because of its consistency with maximizing a richer and perhaps more realistic objective function for the firm's decisions. It may also suggest that the degree of trip chaining for a utility-maximizing choice may be less likely to be determined by a trade-off among utility function components as much as by the fundamental constraints of vehicle size and journey duration and their determinants.

On the basis of the preceding characterization of the firm's preferences for transport pattern alternatives, distance or travel time minimizing vehicle routing would appear to be the most appropriate simplification of the firm's objectives for the transport pattern choice for a given set of consignments. This simplification may actually be employed by firms themselves to facilitate making these complicated choices. This simplification will also be especially appropriate if the costs and level of service affect only the choice of the shipments to be delivered or if the firm only considers transport pattern alternatives which are acceptable in terms of meeting its other objectives.

Transport Pattern Alternatives and Constraints

The set of transport pattern alternatives available to a firm consists of all possible allocations of deliveries to vehicle routes and trips which do not violate the relevant constraints on the supply of goods transport. The alternatives for these choices may vary along all the dimensions of shipment selections and vehicle routing and scheduling discussed previously.

A wide variety of complex constraints may interact to restrict feasible transport pattern alternatives. Resource constraints include those on availability of vehicles and drivers and vehicle load capacity. Vehicle type may also be important when special purpose vehicles are needed or utilized. Important temporal constraints include those on transport pattern and tour duration. These constraints may stem from the firm's hours of operation, driver work rules, or customer requirements. The latter may also place important constraints on shipment pattern selection, delivery timing, sequencing, and reliability.

Operational constraints on the use of transport facilities may include those on the use of the transport network, parking, and priorities in depot operations. Of course, there are also some fundamental physical constraints which require that goods be loaded before they are unloaded, that trips be connected end to end, and other similar logical requirements.

There are at least two important reasons why it is difficult to generalize about the effect of constraints on goods vehicle traffic patterns. The first is that the effect of the constraints depends on the unique characteristics of the decision problem. A second reason why it's hard to generalize about their effect is that many of these constraints do not apply to any single potential delivery or goods vehicle trip; rather, they place restrictions on groups of deliveries and/or trips. Thus, the constraints are another cause of the interdependence of goods vehicle trips. Despite the difficulty in identifying their specific effects, there can be no question that these constraints are among the principal determinants of the frequency and location of urban goods vehicle trips.

Although the constraints limit the feasible transport pattern choice alternatives, it would be mistaken to conclude that they reduce the number of feasible transport pattern alternatives to a small number. Table 3.2-3, based on computations which are described in an appendix to this chapter, shows an estimate of the total number of vehicle routing alternatives for making deliveries to from 1 to n destinations, where n is determined by the constraints. In considering the values in the table, it should be kept in mind that the number of destinations actually visted in an average transport pattern for many activities is at least 10.[22] Further, it is likely that number of alternative consignments considered for incorporation in a daily transport pattern is larger than the number actually chosen. These estimates do not reflect the effects of the constraints of vehicle capacity and tour duration which clearly reduce the number of feasible alternatives. Nevertheless, the computation in the appendix makes it obvious that, even with moderate constraints, the typical transport pattern choice problem will be characterized by very large numbers of alternatives. Therefore, it would be thoroughly implausible to conclude that the firm considers more than a tiny fraction of the potential alternatives.

In order to explain transport pattern choices, it is necessary to identify the subset of alternatives that are actually considered. Reference to the description of

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[22]See, for example, Wilbur Smith, et al. (1969), p. 21.

Table 3.2-3

Total Number of Transport Pattern Alternatives with up to n Destinations

n	T_n
1	2
2	7
3	40
4	317
5	3,166
6	37,987
7	530,972
8	8,495,545
9	$1,532 \times 10^8$
10	$3,063 \times 10^9$

methods employed to solve vehicle routing and scheduling problems suggests that this issue can be considered further in the context of the firm's choice process.

The Choice Process

The preceding discussion has shown that transport pattern choices are made with respect to multiple and possibly complicated objectives and in the presence of multiple constraints. Also, at least some of the attributes of the alternatives exhibit stochastic variation which introduces uncertainty in the assessment of their utility. As a result, it is clear that it is difficult for firms to identify, evaluate, and select the best alternatives. The transport pattern choice problem is further complicated by the combinatorially explosive number of alternatives which make it clear that, with rare exceptions, it is impossible for the decision maker to consider more than a tiny subset of the feasible alternatives.

These characteristics, which render the transport pattern choice problem complex, provide a basis for conceptualizing the underlying choice process as probabilistic rather than deterministic. A probabilistic choice mechanism is required to explain the fact that individuals (or firms) "faced with a choice among complex alternatives ... often exhibit inconsistency. That is, they do not always select the same alternative under seemingly identical conditions." (Sattath and Tversky, 1976, p.79). In the case of a firm's transport pattern decisions, probabilistic choice behavior may arise from uncertain utilities, hidden (unmeasured) attributes, imperfect knowledge, incomplete or incorrect evaluations of alternatives, and variation in the set of alternatives actually considered.

Consideration of the methods of vehicle routing and scheduling discussed previously suggests that prevalent journey planning procedures entail a multi-stage process of enumerating and comparing the subset of alternatives that are considered. For example, the savings criterion and the proximity method, employ distance metrics in order to select a branch or class of alternatives for further consideration in subsequent stages of the choice process. Although the particular enumerative or comparative process may vary from one method to another, common to all is an elimination process which partitions the set of alternatives in a manner which reduces the remaining number of alternatives to be examined. Consequently, a principal characteristic of the vehicle routing and scheduling decision is that the determination of the alternatives to be considered is endogenous to the choice process. In the choice process, the enumeration, evaluation, and selection of alternatives are interdependent and often joint decisions.

As Luce (1959, p. 7) has noted, "it is commonly accepted and probably true, that when such a multi-stage process is needed, the overall results depends significantly upon which intermediate partitionings are employed." For a given method of journey planning, it is likely that the partitionings employed depend upon the characteristics of the specific choice problem and/or an arbitrary starting point. As a result, the problem of identifying the alternatives considered or formulating a valid predictive transport pattern choice model appears to be intractable.

This characterization of transport pattern choice behavior may be differentiated from alternative explanations for decisions involving trip chaining proposed in the urban passenger travel demand literature. The major class of trip chaining models are the Markov decision models described by Nystuen (1959), Horton and Wagner (1969), Sasaki (1972), Gilbert, et al., (1972), Kondo (1974), or Lerman (1977), among others. In Markov models, each trip is determined sequentially on the basis of its or the decisionmaker's prior state. These models in fact falsely assume that decisions are always made about an individual trip rather than an attribute, a class of travel pattern alternatives, or a group of trips or destinations. As Adler (1976) has observed, in Markov models of travel behavior, the travel choices are not in any way based on the expected attributes of the class of remaining, subsequent choices. Not only does this imply that a decisionmaker "will not consider the shortest path for the complete tour as an ordering criterion for sojourns on the tour, but it also implies a stronger assumption that he does not even plan for the number of stops beforehand" (Adler, 1976, pp. 64-65).[23]

In contrast to the view taken in Markov models, Adler (op. cit.) presented the theory that the probability of choosing an entire travel pattern was a function of its utility and that of the other alternatives. This represents a conceptual advance because it formally takes account of the interdependence of all of the trips within a chosen transport pattern. This approach is predicated on the assumption that some set of overall travel pattern alternatives are evaluated and compared. As Luce (1959, p. 133) described it, this decision model will probably apply only for elementary decisions which are not separable into

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[23]Another serious limitation of many Markov models is that they provide no causal explanation for the transition probabilities. Consequently, they can not account for changes in travel responses or offer a framework for statistical analysis of transport patterns. This limitation, however, is not inherent in the modelling concept as evidenced by Ginsburg (1972) and Lerman (1977).

sequences of simpler decisions "but probably not for more complex ones." Consequently, it is difficult to accept this model as a realistic representation of transport pattern choice behavior. Furthermore, this approach can only have predictive power if the set of relevant alternatives can be identified. Although Adler acknowledges that the full set of alternatives is not considered, no choice mechanism is suggested for identifying the alternatives or classes of alternatives that are considered.

It would appear that none of the characterizations of transport pattern decisionmaking described offer a satisfactory representation of the choice process involved or identify the alternatives that are considered. As a result, it may be very difficult to develop adequate choice models of goods vehicle tripmaking.

Implications of Transport Pattern Choice Behavior

The preceding conceptual description of the firm's transport pattern choice behavior has some important implications. The major implication is that all of the firm's short-run transport choices are fundamentally interdependent. Specifically, within this behavioral framework, all decisions about a firm's transport pattern including consignment selection, trip generation, and the linkage of trips in tours must be regarded as interrelated. Decisions to serve a given customer on a tour or with a specific vehicle are not taken independently of decisions to serve other customers on the same tour or on another vehicle tour.

The linkage of trips in chains is an important outcome of the urban freight transport pattern choice process. Trip chaining, which clearly increases the efficiency of urban goods transport, reflects the complex spatial interdependencies of trips in the routing and scheduling decisions made by firms. Trip chaining raises a difficult conceptual obstacle to assessing the relationship between goods transport and urban spatial structure because the volume of goods vehicle trips between locations will depend not only on the characteristics of the activities at those locations and their spatial separation, but will also depend upon economic and transport activities taking place in other locations.

Another implication is that a wide variety of constraints influence the firm's transport pattern choices. Assessments of the demand for urban freight transport which fail to take account of these constraints are unlikely to be very accurate or realistic.

The preceding conceptual description of the transport pattern choice process implies that there are not natural divisions of the choice process into simpler, more tractable decision problems with fewer or more clearly defined alternatives. In fact, the structure of an individual firm's choice process would appear to be probabilistic and thus variable in that it adheres to no single set of decompositions or partitions.

A general limitation of this and other characterizations of transport pattern decisions is that they offer insufficient insight into the firm's choice process and the actual alternatives that are considered. As a result, these characterizations offer little help in understanding the relationships between the characteristics of a transport pattern decision problem and the most probable choices -- a major task in providing a useful theory of urban freight transport behavior. It is important to recognize that neither the fact that the choice process is probabilistic nor the fact that the choice process is covert and perhaps impossible to describe, imply that such relationships do not exist. In the next section, a paradigm is introduced which suggests hypotheses of strong relationships among the characteristics of the firm's urban freight transport pattern decisions and the attributes of its choice problems.

3.3 A Paradigm of the Firm's Trip Chaining Behavior

This section presents a paradigm of the firm's trip chaining behavior. This paradigm applies to a simplified decision context in which: (1) the customer demands to be served in a transport pattern choice, the firm's distribution logistic strategy, and the supply of goods vehicles are fixed, (2) delivery of goods is the only transport activity, and it is completely controlled by the firm itself, and (3) the firm's utility is maximized by minimizing the distance/travel time of its delivery vehicles.

The principal objective of this endeavor is the development of an improved understanding of the effect of trip chaining on the important characteristics of goods vehicle trips. The findings resulting from this analysis are intended to provide the basis for a more comprehensive and realistic treatment of the factors influencing urban goods vehicle traffic.

The approach taken has been to consider the vehicle routing problem formulation and rational solution procedures[24] as a paradigm of the firm's behavior in making its short-run transport choices. This approach was suggested because of the close correspondence between the vehicle routing problem and the firm's transport pattern choice problem. This premise makes it possible to utilize relationships between the attributes of optimal or near-optimal solutions and the characteristics of vehicle routing problems as hypotheses linking the determinants and the outcomes of firms' transport pattern choices.

The following discussion of the characteristics of optimal and near-optimal solutions to vehicle routing problems focuses on the determinants of trip and tour generation, delivery costs, and trip distribution, with special emphasis on the effects of trip chaining. Although these attributes are discussed separately, they are interrelated, and an attempt is made to clarify the interdependence of these characteristics of goods vehicle transport patterns.

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[24]Rational solution procedures are meant to include exact methods, heuristics, as well as the better manual methods of journey planning.

3.3.1 Trip Generation

The number of trips, T, generated in delivering N consignments is dependent on N and on M, the number of tours required. If there are n_i consignments delivered on each tour i, where $\Sigma n_i = N$, then tour i will pass through n_i nodes and the depot. Since each tour in an optimal solution to the vehicle routing problem is optimal with respect to the traveling salesman problem, tour i will be comprised of exactly n_i+1 trips. The total number of trips is found by summing the number of trips in each tour over all the tours. As shown in equation 3.17, the number of trips generated is equal to the number of consignments delivered plus the tour frequency.

$$T=\sum_{1}^{M}(n_i+1)=\sum_{1}^{M}n_i+M=N+M \tag{3.17}$$

It should be noted that although the number of trips is a function of the number of shipments from the depot, the locations of the trip origins are not, in general, the same as the origin of the tours. Rather, since the number of depot-based trips is 2M, there will be T-2M=N-M non-depot-based trips, the destinations (and origins) of which will be identical to the destinations of the consignments to be delivered.

If the number of consignments transported to zone i from the depot in zone k is S_i^k, then the number of trips generated in (and attracted to) zone i on tours originating in zone k, T_i^k, is shown below,

$$T_i^k = \begin{cases} S_i^k, & i \neq k \\ S_i^k + M^k, & i = k \end{cases} \tag{3.18}$$

where M^k is the number of tours generated in zone k. Equations 3.17 and 3.18 make it clear that there is a very well-defined relationship between goods vehicle trip generation/attraction and the generation of goods consignments and goods vehicle tours.

The major implication of this discussion is that questions of trip generation are, in reality, questions of consignment and tour frequencies and their respective determinants. This point represents a considerable departure from the literature on urban freight transport in which trip and consignment frequencies are considered independent and in which the issue of tour generation has apparently not yet arisen. In order to develop a better understanding of trip generation and because it is of interest in its own right, we next consider tour frequency and its determinants.

3.3.2 Tour Frequency

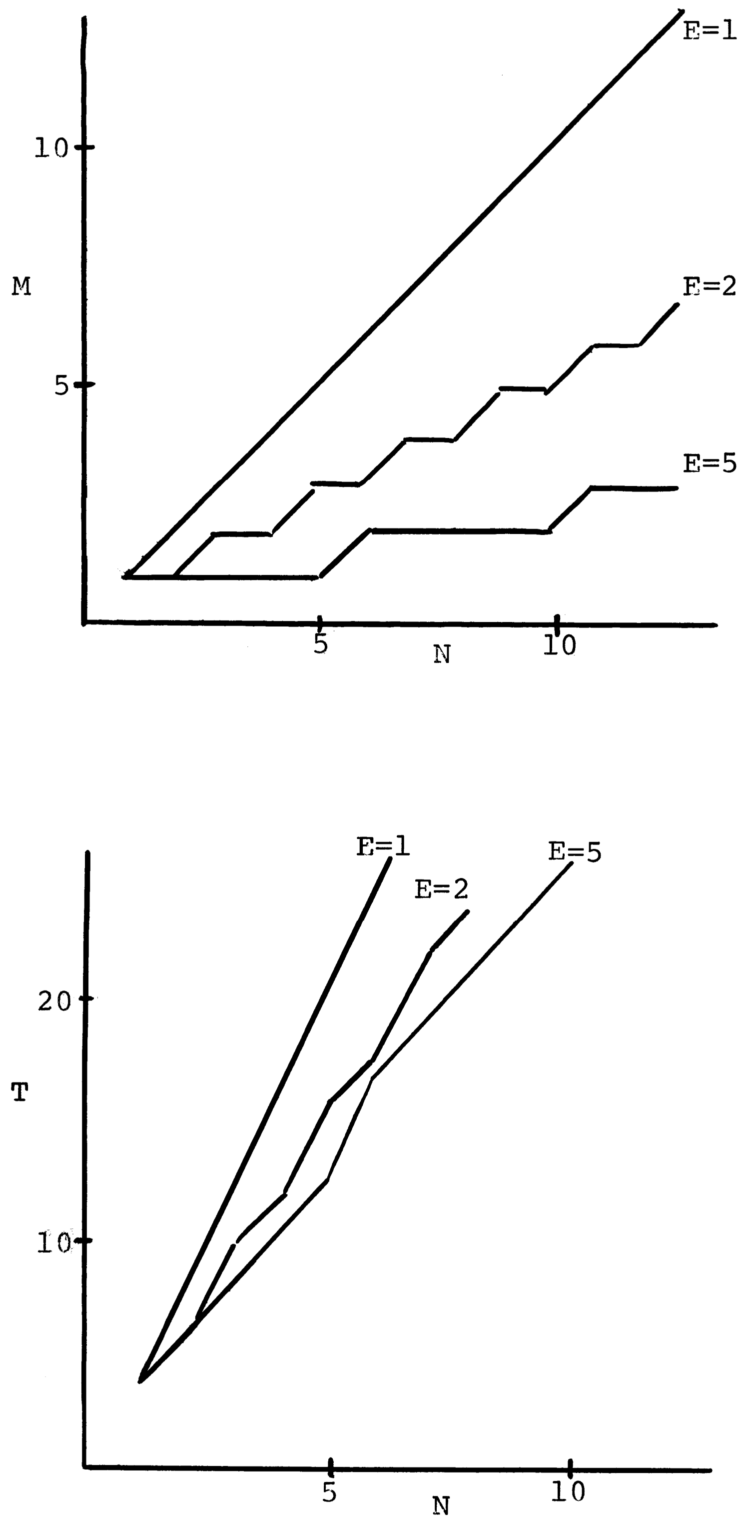
The number of tours in an optimal solution to a truck dispatching problem is a function of the average maximum number of consignments, E, that can be delivered on a single tour. An estimate of tour frequency, M, is provided by dividing the total number of consignments to be delivered, N, by the average maximum number of consignments that can be delivered per tour. Since the number of tours must be an integer, it is easy to see that $M = N/E$ if E is a perfect divisor of N and $M = M_0 + 1$ otherwise, where M_0 is the integer part of N/E. This result is also mentioned in Tyagi (1968).

This simple relationship and the resulting trip generation relationship (substituting for M in equation 3.19) are illustrated in Figure 3.3-1 in which tour and trip frequencies are graphed as functions of N for different values of E. As shown there, the number of tours increases at a slower rate than N, and the number of trips increases at a somewhat higher rate than the number of shipments.

Since $1 \le E \le N$, it follows that the number of tours and the number of trips for a given shipment pattern are bounded from above and below. Specifically, $1 \le M \le N$ and $N+1 \le T \le 2N$ for all values of E.

Figure 3.3-1

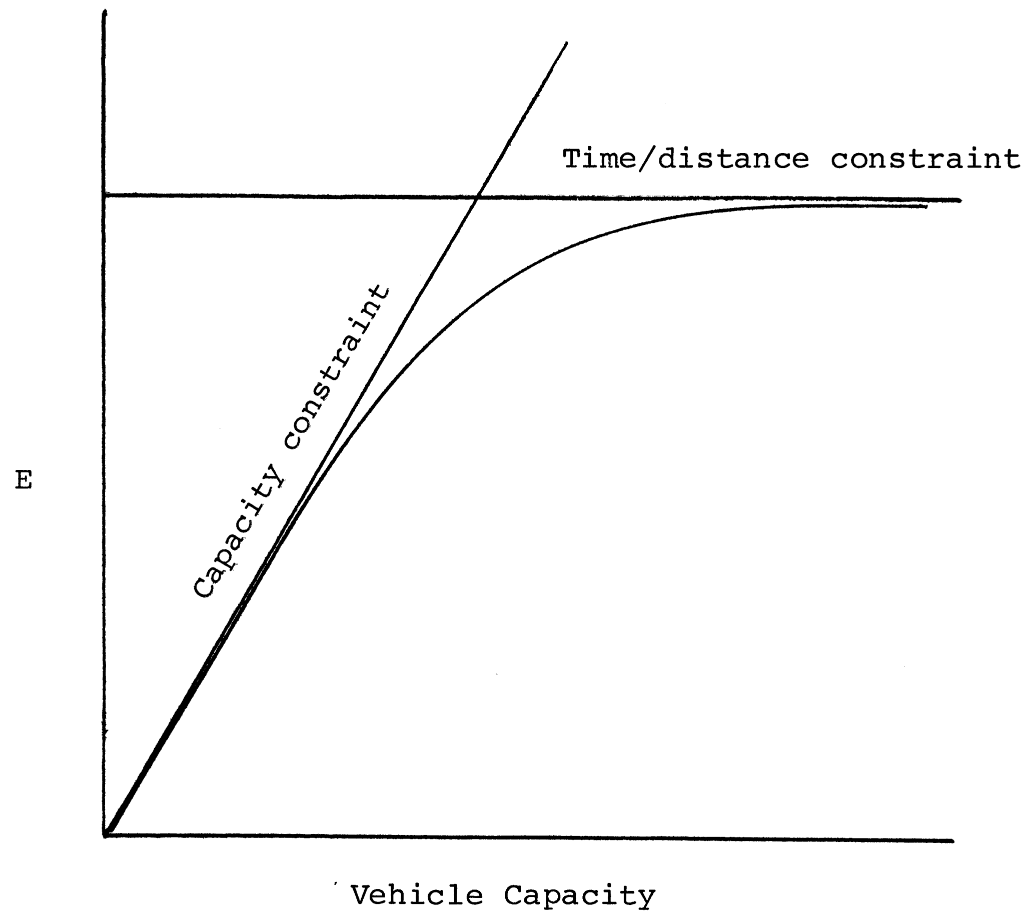
Tour and Trip Frequencies as Functions of the Number of Customers Served



The degree of trip chaining has a clear effect upon tour and trip frequencies (holding the number of deliveries constant) with a much larger relative effect upon the latter. Clearly factors which affect the degree of trip chaining are primary determinants of tour frequency and will also have an impact on trip generation. Consequently, since trip chaining is positively related to vehicle capacity, there will be an inverse relationship between vehicle capacity and tour and trip generation, and an increase in vehicle capacity will lead to a greater percentage reduction in tour generation than in trip generation. Similarly, an increase in the average size of deliveries will reduce E and lead to an increase in tour and trip generation with a greater relative increase in the former quantity.

As Eilon, et al. (1971, p. 173) have noted, the average number of customers served per tour "is determined by all the constraints acting separately or together, the main constraints being the vehicle capacity and the maximum time for the duration of each route." Figure 3.3-2, from Eilon, et al. (1971, p. 235), illustrates the relationship between E and these constraints as derived from simulation experiments. For low values along the time/distance axis, the vehicle's capacity is the limiting quantity. If capacity, VC, is the limiting constraint and q is the size

Figure 3.3- 2 The Effect of Constraints on the Number of Customer Demands Served per Tour



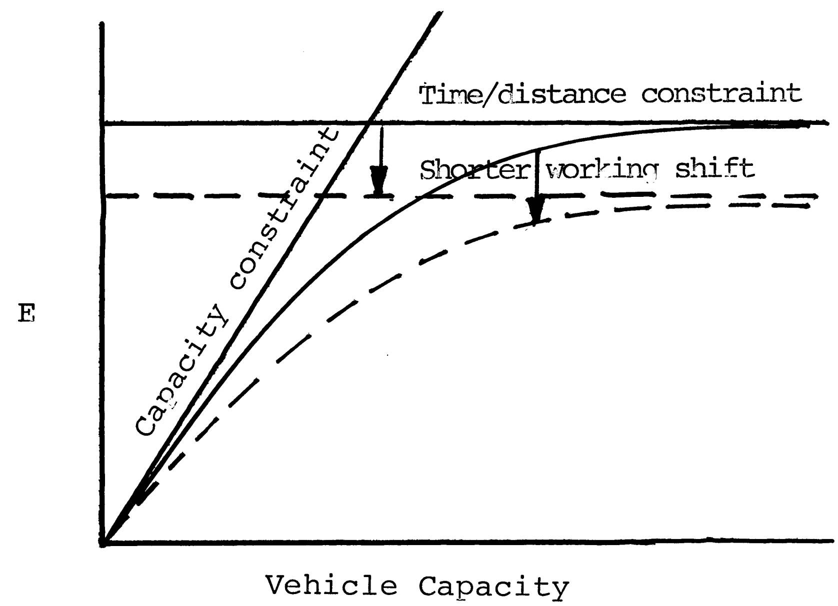
of an average customer demand, then E = the integer part of VC/q.

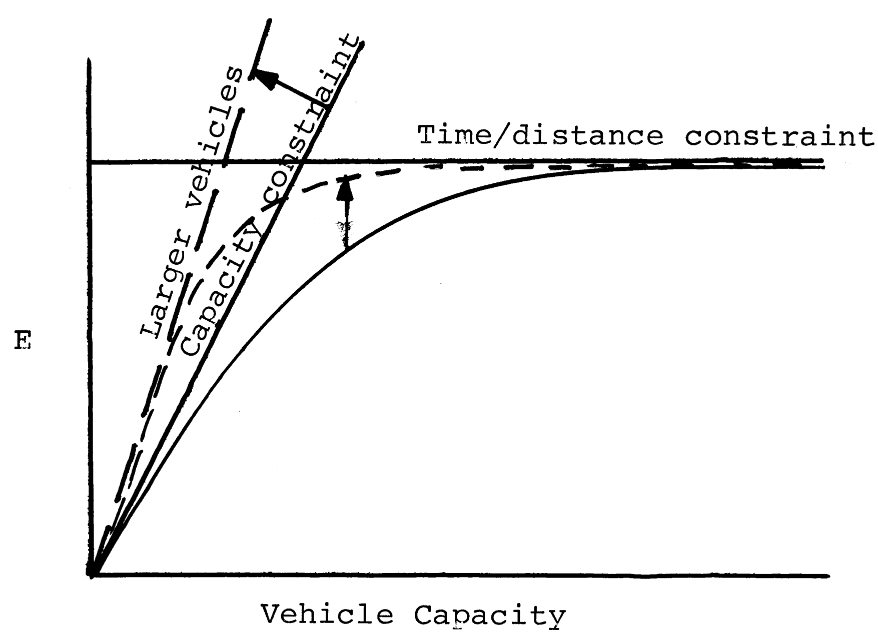
At large vehicle capacities, the time or distance associated with the tour becomes limiting. Tour duration and length are functions of the distances from the depot to the customers as will be discussed subsequently. If time rather than distance is the constraint, the average maximum number of customers served may also be a function of the time required to perform the non-driving tasks which are part of goods delivery, the customers' specific level of service requirements, labor work rules, or some combination of these factors.

Tour duration should not be confused with transport pattern duration, although in the case of 1-tour transport patterns they will be equal. Constraints on transport pattern duration are probably more common than constraints on tour duration. Constraints on transport pattern duration may often impact the degree of trip chaining indirectly by limiting the consignment frequency.

Figure 3.3-3 illustrates possible consequences on the degree of trip chaining resulting from a shortening of working hours for drivers and deliverymen and from the utilization of vehicles with larger capacities. In the

Figure 3.3-3 Possible Effects on Trip Chaining Resulting from Changes in Working Hours or Vehicle Capacities





former case, the average number of customers served per tour declines, but only in the range of vehicle capacities for which the length of the shift is the binding constraint. In the latter case, the degree of trip chaining increases because of the expansion of vehicle capacity, but this effect is also limited to the range of vehicle capacities in which the capacity constraint is the limiting factor.

3.3.3 Transport Pattern Lengths and Trip Lengths as a Function of Shipment Lengths

An important relationship which is strongly influenced by trip chaining is that between the distance traversed by a fleet of vehicles in a transport pattern and the respective distances of customers from the depot. This relationship is fundamental to measuring the costs of urban freight distribution. Factors which influence this relationship are also indicative of the determinants of spatial patterns of goods vehicle trips.

Eilon, et al. (1971) have devised a model which gives an estimate of the expected distances of solutions to vehicle routing problems. The model is based on the analysis of the expected length of optimal traveling salesman tours which are the components of optimal solutions to these problems.[25] The model was calibrated on a data set consisting of a large number of near-optimal solutions to vehicle routing problems with systematically differing characteristics including randomly generated demands of normally distributed size.

The results of model estimation (Eilon et al., op. cit., p. 125) indicated that "there is a very well defined relationship between" the sum of the route lengths (tour lengths), the sum of the radial distances, and the average maximum number of customers served per tour. Further, the relationship was found to be relatively stable with respect to varying depot location and market area shapes.

The model is shown below as equation 3.19

$$D_o = [1.8D_r/E]+1.1\sqrt{a}\sqrt{D_r} \tag{3.19}$$

where D_o = the total distance travelled by the vehicle fleet in a solution to the vehicle routing problem.

D_r = the sum of the radial distances from the depot to the demand points.

E = average maximum number of customers

[25]For this reason the "model" produces good results only when the assumption of non-intersecting routes is valid and this occurs only when the constraints existing in the actual distribution problem are mild," Eilon, et al. (1971, p. 174).

served per tour

and a = the side of a square in which the depot and customers are distributed.

The relationship between D_o and D_r as a parametric function of E is shown in Figure 3.3-4. As indicated in the graph, the distance travelled by a fleet of vehicles is bounded from above when $E = 1$ by $D_o = 2D_r$ and from below for $E \geq N$, the number of customers, by the length of the travelling salesman tour passing through the N points and the depot.[26]

This model can be used to characterize the effect of trip chaining on the relationship between the mean goods vehicle trip length and the mean length of shipment. The distance travelled by the vehicle fleet is equal to the number of trips multiplied by their average length $\bar{d}_t$. Drawing upon a prior discussion, the number of trips can be approximated as the product of the average number of trips/tour, E+1, and the approximate number of tours, N/E, in a transport pattern yielding (3.20) below.

$$D_o = (N/E)(E+1)\ \bar{d}_t \tag{3.20}$$

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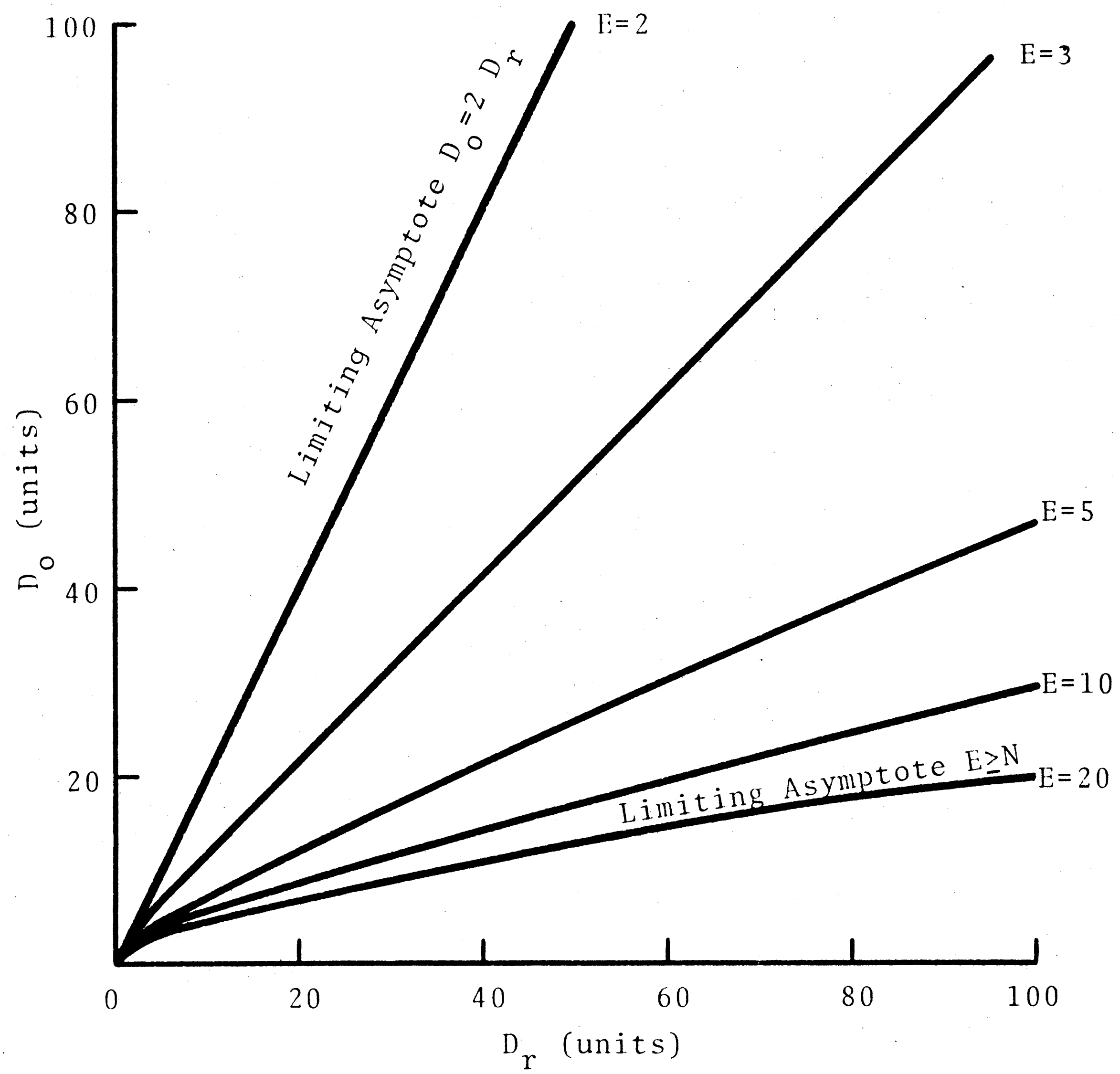
[26]If E is a random variable instead of a constant, the overall distance covered by the fleet will be larger and as Eilon, et al. (op. cit.) point out, an (improved) estimate of the expected distance can be obtained by substituting the expectation of E in (3.19).

Figure 3.3-4

Distance Travelled as a Function of the Sum of

the Radial Distances



Source: After Eilon, et. al.,(1971,p.176)

The sum of the radial distances to the customers can be expressed as the product of the number of customers and their average distance from the depot which is equal to the average shipment length, $\bar{d}_s$.

$$D_r = N\bar{d}_s \tag{3.21}$$

Substituting (3.20) and (3.21) into (3.19) and solving for $\bar{d}_t$ gives (3.22) which follows.

$$\bar{d}_t = [\, 1.8\bar{d}_s/(E+1) \,] + 1.1\sqrt{a}\sqrt{\bar{d}_s}E \,/\, (\sqrt{N}(E+1)) \tag{3.22}$$

As would be expected, the bounds on $\bar{d}_t$ are different that those on D_o. In particular, the most inefficient delivery pattern from the point of view of tour length is the pattern in which each shipment is transported on a tour comprised of two trips. Since the outbound trip is the same length as the return trip and both are equal to the shipment length, it is clear that $\bar{d}_t \leq \bar{d}_s$. The approximation of equation 3.22 is in agreement with this condition for all but the smallest values of N.

The above expression is of interest as much for its identification of variables as for its specification of their functional relationships to the mean trip length. The number of customers served, their respective distances from the depot, the size of the firm's market area, and the average maximum degree of trip chaining are indicated as primary determinants of goods vehicle trip lengths. This conclusion makes it clear that the average length of a specific trip is not independent of decisions about other trips and their determinants.

The relationships between the average trip length and the right-hand side variables of equation 3.22 are illustrated in Figure 3.3-5 which graphs $\bar{d}_t$ as a function of $\bar{d}_s$, E, a, and N, holding the omitted variables constant. We observe from the figure and by inspection of (3.22) that $\bar{d}_t$ is an increasing function of $\bar{d}_s$ and a, and a decreasing function of E and N.

A numerical assessment of the effect of changes in these variables upon mean goods vehicle trip lengths is provided by calculating the relevant elasticities. Estimates of these (point) elasticities evaluated at representative values of the variables are contained in Table 3.3-1.

Intuitively, these results seem reasonable. The mean trip length increases as the firm's market area increases in terms of the mean distance to its customers, holding

Figure 3.3-5

Determinants of Mean Vehicle Trip Lengths

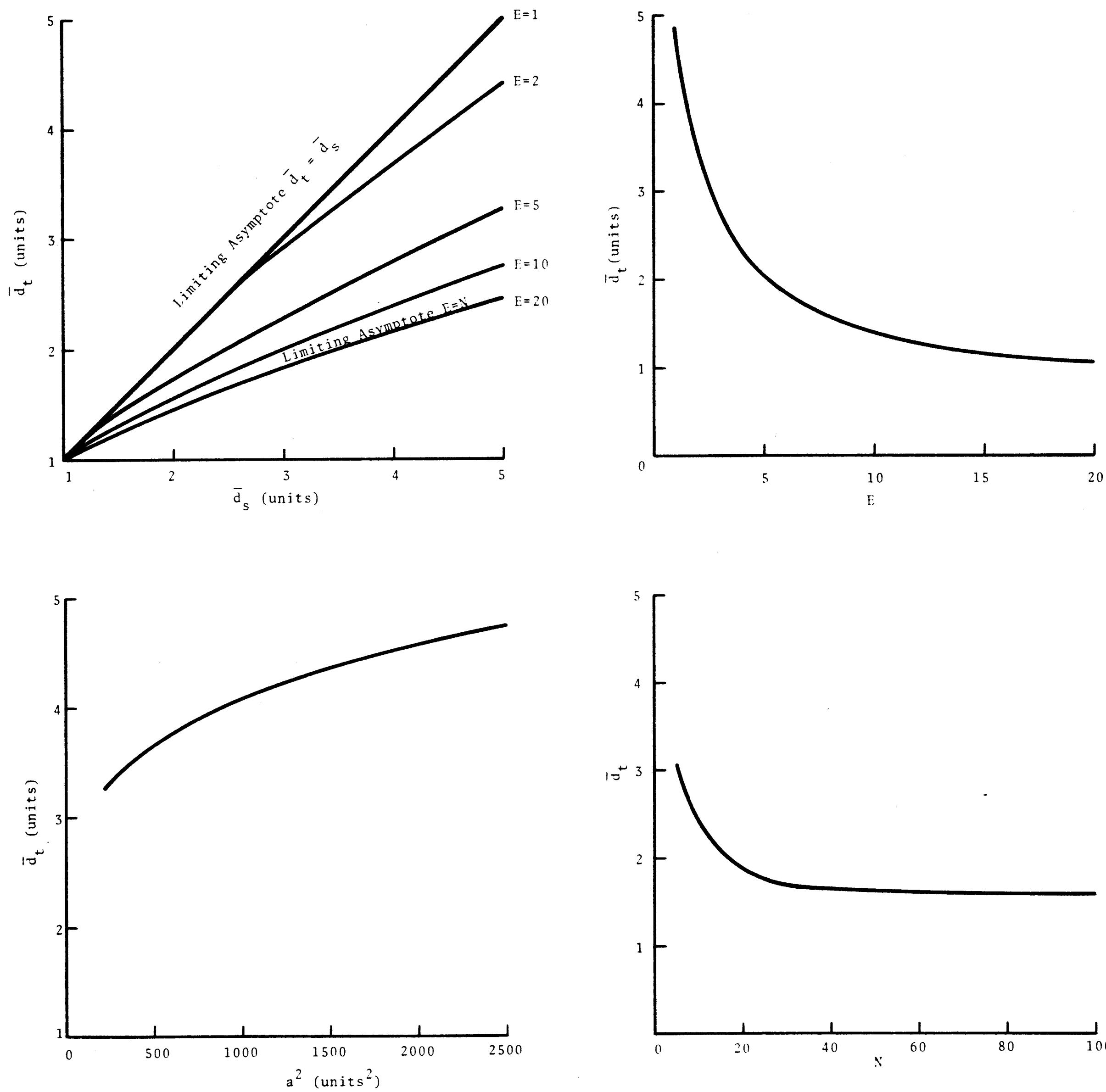


Table 3.3-1 Elasticity of Mean Vehicle Trip Length with respect to Key Variables

Variable	Range of Elasticity	Representative Value*
$\bar{d}_s$	$1/2 < E_{\bar{d}_s} < 1$	.725
E	$-1 < E_E < -1/2$	-.83
a^2	$0 < E_{a^2} < 1/4$	.14
N	$-1/2 < E_N < 0$	-.275

* $\bar{d}_s = 25$

$E = 5$

$a^2 = 100$

$N = 25$

constant the number of customers. If the average distance to the firm's customers is held constant, but the demands are distributed in a larger area, there will also be an increase in the average length of goods vehicle trips. However, the effect of the increase will be considerably smaller than the effect of an equivalent percentage increase in average shipment length. The mean trip length declines considerably as E, the degree of trip chaining, increases and also decreases, although at a lower rate, as the number of customers served in the transport pattern increases, holding all other factors constant.

Because E may be determined by vehicle capacities, average shipment sizes, and network travel times, these factors may also be determinants of average trip lengths. Inferentially, these and the above factors are also likely to be determinants of urban delivery costs and spatial patterns of goods vehicle trips. These are the next consequences of vehicle routing and scheduling decisions to be considered.

3.3.4 The Costs of Urban Freight Shipments

The costs of making urban freight deliveries are substantially influenced by trip chaining. Although the effect of trip chaining is typically to reduce costs, it is easy to see that ascertaining the costs of each delivery in a multi-destination, multi-tour transport pattern poses certain conceptual and empirical difficulties. The following passage from Webb (1968, p. 311-92), who performed an early and inconclusive study, indicates some of the important aspects of this problem.

> "With the introduction of intermediate journeys a combinatorial, as opposed to simple non-linear element is introduced into transport costs. A small increase to an existing delivery or collection quantity may add an insignificant and undetectable amount to actual transport cost if the vehicle has spare capacity, but might add the cost of a special journey if there is no space capacity. Similarly, an extra delivery or collection may cost virtually nothing if a vehicle with adequate spare capacity is already due to pass, or as much as the cost as a special journey if not. Knowledge of the size and position of a delivery or collection is insufficient to specify the basic transport cost incurred."

With the exception of Webb (op. cit.) and Eilon, et al. (1971), prior work on depot location, urban commodity flows, and urban goods vehicle trips has tended to ignore this problem. Prior studies have assumed (1) that multi-destination tours do not exist; (2) that delivery costs are a function of the characteristics of the actual trip on which the delivery was made; or (3) that delivery costs are a function of the costs of a round trip from the shipper to the receiver without intermediate stops. For the multi-destination tour, it is obvious that assumption (2) underestimates the costs because it ignores the return trip to the depot and assumption (3) is incorrect because it ignores the savings that results from combining deliveries on multi-stop tours. Clearly, an improved notion of the costs of deliveries would be desirable. The preceding analysis of transport pattern decisions and of mean trip lengths offers a foundation for this task.

On conceptual grounds, it is clear that the cost of delivering a particular consignment in a multi-destination, multi-tour transport pattern cannot be divorced from the costs of making all the trips and tours because the optimal (or behavioral) transport pattern choice is influenced by the full set of shipments. In general, the addition or substraction of a shipment from a vehicle routing problem will result in the choice of a different pattern of pairwise trip connections between the remaining nodes. Thus it is necessary to define marginal costs in a manner which is behaviorally realistic.

Since shipments may differ in composition, amount and location, marginal cost will be analyzed for an individual shipment. For this reason and because of discontinuities in the cost function, an incremental rather than an instantaneous, definitional approach is employed. Finally, since adding a shipment to a shipment pattern will often be infeasible in that it may violate constraints such as those on journey duration and vehicle capacity, the marginal cost of a shipment is calculated by subtracting it from the shipment set instead of by adding it.

Let C^*_S equal the firm's total (variable) cost for delivering a set of shipments $S=(S_1 \ldots S_i \ldots S_n)$ to its customers for its transport pattern choice conditional on S. Let $C^*_{S-(i)}$ equal the total (variable) cost for delivering the set of shipments, S-(i), for the firm's transport pattern choice for this smaller shipment set. These transport pattern choices are illustrated with the simple example shown in Figure 3.3-6, in which customer deliveries are made to i, j, and k from the depot D. The marginal cost of shipment i, $MC_{i \varepsilon S}$, is defined below.

$$MC_{i \varepsilon S} = C^*_S - C^*_{S-(i)} \tag{3.23}$$

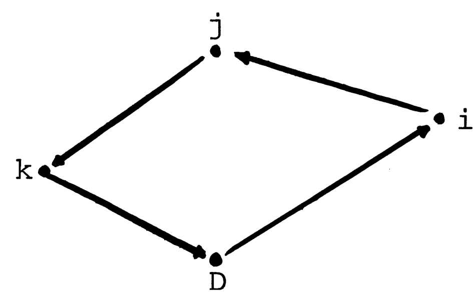
The cost function for a firm's transport pattern presented as equation 3.13 is expressed below as a function of the total distance to be traversed by the goods vehicles and the average speed on the transport network.

$$C = D_O\,[W/sp+OC] + W\,[LV+N(\bar{p}t + \bar{r}t)] \tag{3.24}$$

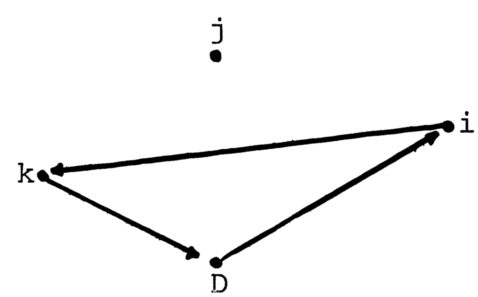
where C = the total (variable) cost
D_O= the total distance traversed by the goods vehicle

Figure 3.3-6

The Transport Pattern Choice
for S=(i,j,k)



The Transport Pattern Choice
for S=(i,k)



W = the drivers wage rate
sp = the average travel speed on the road network
OC = the vehicle operating cost per unit distance
L = the loading/unloading time per unit volume of freight
N = the number of shipments
$(\overline{pt}+\overline{rt})$ = the other time elements required to make deliveries as defined previously

Utilizing equation 3.24, the cost of the transport pattern chosen for S=(i, j, k) can be written as

$$C^*_S = [d_{D,i} + d_{i,j} + d_{j,k} + d_{k,D}][W/sp+OC] + W[L(V_i + V_j + V_k) + 3(\overline{pt} + \overline{rt})] \quad (3.25)$$

where the $d_{i,j}$ = the distance beweem nodes i and j and V_i = the volume of consignment i.

Suppose we wish to calculate the marginal cost of delivery j. This requires knowledge of the firm's optimal transport pattern choice for S-(j)=(i, k), indicated in Figure 3.3-6, which is easy to guess in this simple case. $C^*_{S-(j)}$ is written as follows.

$$C^*_{S-(j)} = [d_{D,i} + d_{i,k} + d_{k,D}][W/sp+OC] + W[L(V_i + V_k) + 2(\overline{pt} + \overline{rt})] \quad (3.26)$$

Therefore, the marginal cost of the jth shipment, $MC_{j\varepsilon S}$, for shipment pattern S is

$$MC_{j \varepsilon S} = [d_{i,j} + d_{j,k} - d_{i,k}][W/sp+OC] + W[LV_j + (\bar{p}t + \bar{r}t)] \quad (3.27)$$

In the case of a multi-tour transport pattern, changes in the pattern may be much larger and more difficult to characterize, and it is harder to intuit the effects on marginal costs. However, assuming that equation 3.19 applies, the general expression shown below approximates the marginal cost of shipment j.

$$MC_{j \varepsilon S} = [W/sp+OC][(1.8d_{D,j}/E) + 1.1\sqrt{a}(\sqrt{D_r} - \sqrt{D_r - d_{D,j}})] + W[LV_j + \bar{p}t + \bar{r}t] \quad (3.28)$$

The marginal cost of delivery j is a function of its size and the length of haul from the depot. The marginal cost of a delivery also declines with the degree of trip chaining. Equation 3.28 directly illustrates that the cost of a shipment will vary with the other shipments in the transport pattern.

The calculation of the marginal costs for any given shipment would obviously be onerous for firms facing transport pattern choice decisions of modest size because of the need to solve a hypothetical vehicle routing and scheduling problem to obtain an answer. Consequently, Webb's contention that knowledge of the location and amount of a delivery are insufficient to specify the basic cost can be extended to the observation that the costs of transporting individual shipments are not directly observable from data on the firm's chosen transport pattern choices alternatives, but depend upon the transport pattern choices that it would make if the shipments were not made. The nature of the assessment required makes it implausible that firms are generally cognizant of the marginal costs of urban freight deliveries.

Irrespective of the type of pricing policy employed, firms are much more likely to base delivery charges on average transport costs for various categories of shipment size and destination. Therefore, it seems logical to examine the firm's average costs for deliveries as a means of obtaining insights into the structure of urban freight transport delivery charges.

The average costs of making an urban freight transport delivery can also be estimated by utilizing the approximation for the total distance travelled by goods vehicles in a multi-destination, multi-tour transport pattern and the cost function given in (3.24). Substituting (3.21) into (3.19), substituting the result for D_O in (3.24), and dividing through by the number of shipments, N, results in the following equation for the average delivery cost, $\bar{C}$.

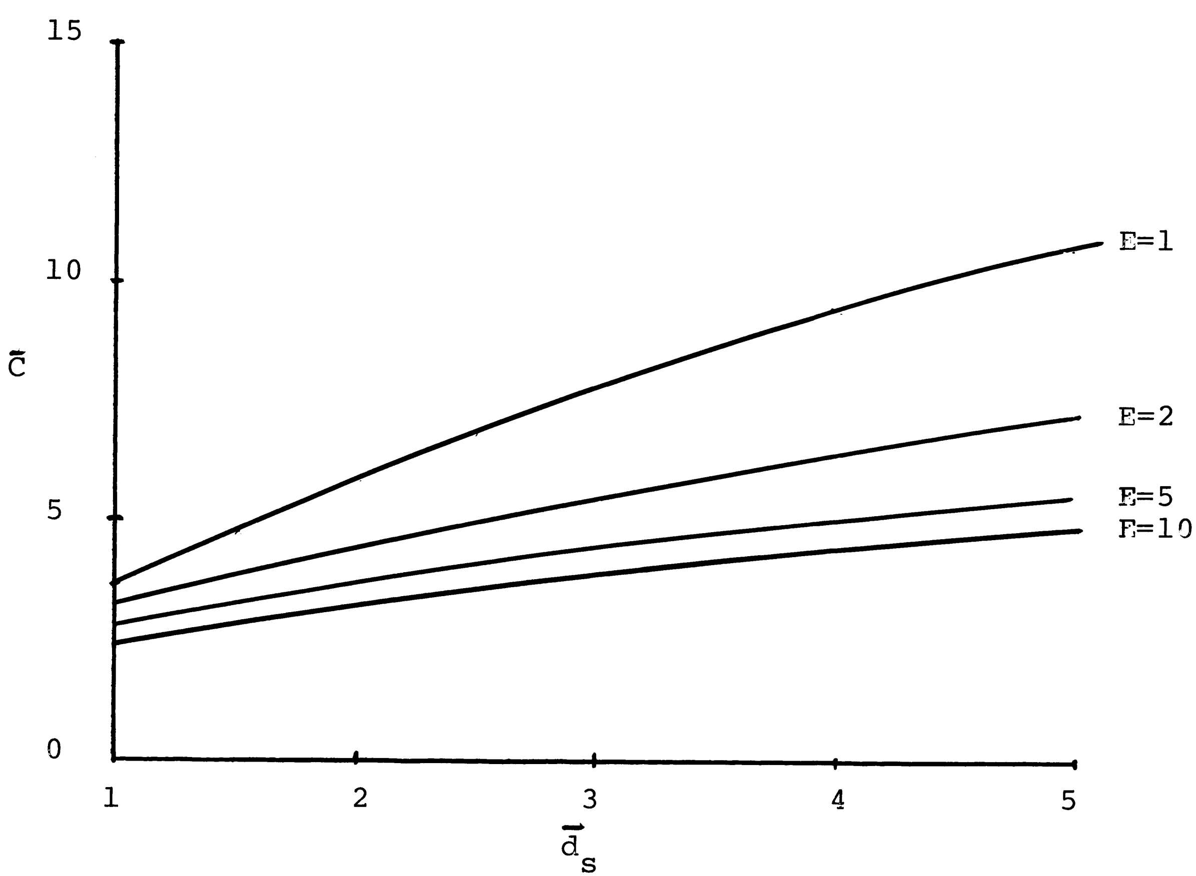
$$\bar{C} = [(1.8\bar{d}_s/E) + 1.1\sqrt{a}\sqrt{\bar{d}_s}/\sqrt{N}][W/sp + OC] + W[LV/N + (\bar{p}t + \bar{r}t)] \quad (3.29)$$

This function illustrates that the average cost of a shipment increases with respect to its distance from the depot and decreases with the degree of trip chaining. Additionally, average shipment costs decline with the number of customers served and increase with the size of the firm's market area, holding all other factors constant. The average cost equation is important because it may justify the use of functions of the distance or travel time between carrier and receiver to represent the cost of making shipments in complex transport patterns.

The form of the relationship between $\bar{C}$ and $\bar{d}_s$ is indicated in Figure 3.3-7 for different values of E. The curves in the figure indicate that the relationship between $\bar{C}$ and $\bar{d}_s$ is approximately linear at least for some small values of E. Following Eilon <u>et al</u>. (1971) note that there will be an approximately linear relationship between these variables when the first term in the first bracket of equation 3.29 is considerably larger than the second term as indicated below.

Figure 3.3-7

Average Delivery Costs as a Function of Shipment Distance



$$\frac{1.8\bar{d}_s}{E} \gg \frac{1.1\sqrt{a}\sqrt{\bar{d}_s}}{\sqrt{N}} \tag{3.30}$$

With cross-multiplication this expression becomes (3.31).

$$\sqrt{N} \gg \frac{1.1\sqrt{a}E}{1.8\sqrt{\bar{d}_s}} \tag{3.31}$$

For a square market area, the expected distance between the depot and a random point is .383a.[27] Substituting this value for d and squaring, results in the condition indicated below.

$$N \gg E^2 \tag{3.32}$$

Thus for N considerably larger than E^2, average (variable) costs will be well approximated by a linear function of shipment distance or travel time with a slope of 1.8/E. When this condition is not fulfilled (i.e, when E is large), shipment costs will increase at a less than linear rate with the length of shipment.[28]

Because trip chaining reduces transport costs and because the size of the reduction increases with distance, we may hypothesize that the effect of trip chaining is to

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[27]This result is derived by Eilon *et al*. (1971, p. 158).
[28]Substitution of $\bar{d}_s$ = $sp\bar{t}_s$ in equation 3.29 where $\bar{t}_s$ is the length of haul expressed in travel time and similar algebra illustrates that the same conditions hold for the relationship between costs and travel time.

heighten but also to flatten the spatial demand cone for the firm. Assuming the presence of alternative suppliers and probablistic choice behavior for consumers, it may also be inferred that the effect of trip chaining is to increase the degree to which the trade areas of competing firms overlap. Further, the fact that trip chaining flattens cost curves and thus selling prices, may provide at least a partial explanation for the prevalence of equal-delivered pricing policies in metropolitan areas.

The structure of urban freight transport costs would also appear to result in agglomerative forces influencing the location of producers and consumers within metropolitan areas. As suggested by the marginal cost analysis, consumers of goods located in close proximity to other consumers of similar goods may experience lower transport costs and more rapid and reliable deliveries than is likely at locations which are remote from other consumers.[29] This point and the structure of the average cost function suggest locational variation in the costs of making urban freight shipments of identical length because of variation in the density of customers in the market areas of differently

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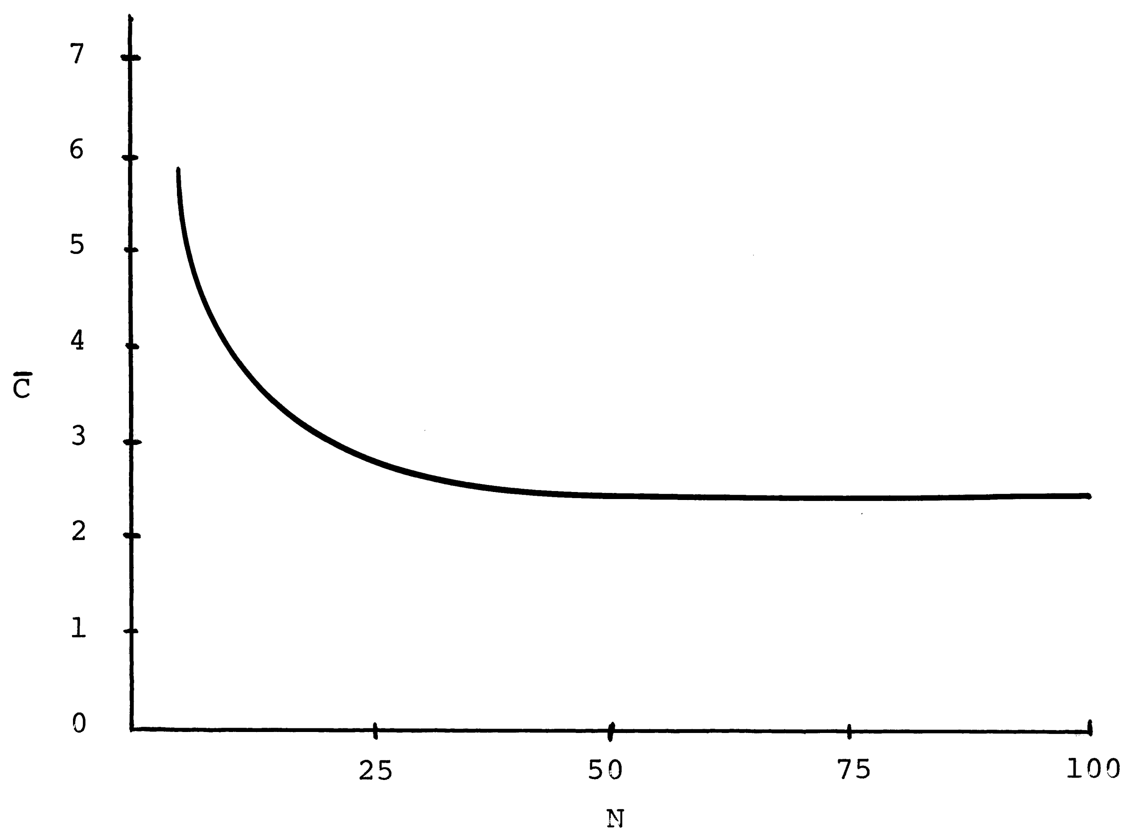
[29]A related locational factor was articulated by Nystuen (1959) who observed that one reason why retail stores co-locate is to take advantage of customers' desires to make multi-stop shopping trips.

situated firms. Also, shorter shipment lengths are expected in the smaller market areas in central areas. Although these factors should result in lower costs in the dense, central areas of metropolitan regions, the cost differences may be offset by lower transport network speeds.

The average (variable) cost function derived above provides the basis for a qualified conclusion that trip chaining behavior results in economies of scale in the production of urban freight transport. This conclusion rests on the finding, displayed graphically in Figure 3.3-8, that the average costs of urban freight shipments decline as a function of the number of customers served which is presumed to be closely related to firm size. In addition, greater opportunities for achieving a high degree of trip chaining and more efficient vehicle tours are also likely to be concomitants of scale. Therefore, it seems that trip chaining offers a possible explanation for Starkie's (1967) empirical results on the presence of economies of scale in trip generation at manufacturing plants. However, this relationship is valid only over the range of N which can be delivered with the firm's fixed resources of vehicles and labor, etc. and, therefore, it is not suggested that these scale economies exist outside this limited range.

Figure 3.3-8

Average Delivery Cost as a Function of the Number of Deliveries per Transport Pattern



Economies of scale in transport are also likely to result if larger shipment sizes are associated with larger firms or with higher levels of output for the same firm. For this reason, the costs of delivery per unit volume of consignments will also be reduced. The costs of shipments will be only weakly related to their size except to the extent that vehicle capacity rather than journey duration limits the degree of trip chaining. Thus, in this situation as well, scale economies will be present until the first binding constraint is encountered.

A further qualification must also be mentioned. Since this analysis has been based on a somewhat narrow view of costs leaving out administrative expenses and possibly other factors which vary with scale, caution is warranted with respect to the conclusiveness of these arguments.[30]

3.3.5 Trip Distribution

Rational vehicle routing behavior exerts a profound influence upon the spatial distribution of goods vehicle trips. As indicated in the preceding discussion, distance (or cost) minimizing routing which leads to the linkage of

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[30]For a debate on the presence of economies of scale in road goods transport which illustrates some of the more subtle issues, see Chisholm (1959) and Harrison (1963).

trips in chains significantly affects origin-destination patterns and results in a considerable reduction in trip lengths as customers are linked to one another instead of being served singly on trips emanating directly from the depot.

Trip chaining introduces complex interdependence into the spatial distribution of goods vehicle trips in that the choice to make a trip from node i to node j (or the volume of trips from zone i to zone j) is not independent of decisions about the trips on which the firm's other customers are served. For this reason trip chaining would appear to invalidate a basic assumption of conventional trip distribution/destination choice theory. Even if we assume as a necessary, if undesirable, simplification that the choice of a trip destination (or origin) for each trip origin (or destination) is independent of the choices for all other trips, it is not difficult to see that models based on the hypothesis that trip distribution is solely a function of the characteristics of the origin and alternative trip destinations (or of the destination and alternative trip origins) and their spatial separation may be misspecified and fail to capture important behavioral effects.

To understand goods vehicle trip distribution, it is necessary to consider the fundamental theoretical question of whether vehicle routing decisions result in any systematic relationships in the origin-destination pattern of goods vehicle trips at the disaggregate firm level. Consideration of the procedures used in making these decisions suggests that such relationships may indeed exist, that the conventional gravity model trip distribution hypothesis is only a crude approximation, and that more complex hypotheses and unresolved issues stem from the same line of reasoning.

As suggested by Gaskell (1967, p. 282) the central property of virtually any systematic method of solving the vehicle routing problem is "the measure of priority for consideration which is attached" to forming the links between pairs of customers. In most approaches to the vehicle routing and scheduling problem, the priority criterion for forming or replacing links is computed for one or more alternatives. The most favorable linkage is formed or replaced subject to its feasibility in terms of the problem constraints. Almost all of the methods employed by manual dispatchers and computer algorithms to obtain distance minimizing solutions use measures which are a function of the distance between customers and give preference to connections between proximate nodes. As a result, it is hypothesized that the likelihood that two nodes will be joined by a trip will be a function of their spatial separation. Intuitively it would seem that the closer that two delivery points are, the more likely they are to be served on the same tour and the more likely that they will be joined together on that tour.

To formalize this proposition, recall that for a given shipment pattern and tour frequency,[31] the origins and destinations of all the trips are completely determined. Thus, the disaggregate trip distribution question equates to the choice of a trip destination for each trip origin in the pattern. Let p_{ij}^k equal the probability that a trip originating at node i will terminate node j on a tour in a transport pattern which originates at node k. Then p_{ij}^k can be expressed as a function of their distance apart as shown below:

$$p_{ij}^k = f(d_{ij}) \qquad (3.33)$$

The notion that distance-minimizing vehicle routing behavior results in a relationship between the distance

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[31]This hypotheses is framed in probablistic terms for reasons given previously and because the constraints prohibit deterministic solutions in which nearest neighbor or other priority rules are always feasible.

between two customers and the probability of their being linked is supported by consideration of the reduction in total distance that is achieved by connecting those points on the same tour. Recall from Figure 3.2-1 that the savings, SAV_{ij}^{k} with respect to the depot k is given by equation 3.34 which follows.

$$SAV_{ij}^{k} = d_{ki} + d_{kj} - d_{ij} \tag{3.34}$$

As indicated by (3.34), the savings increases as the distance between i and j decreases, so that assigning the priority of trip linkages according to the savings criterion would lead, ceteris paribus, to a greater probability of linking nodes which are closer to each other.

The relative importance of d_{ij} as a determinant of p_{ij}^{k} may depend on firm behavior (the method of solution) and the characteristics of the vehicle routing problem. At one extreme with the proximity method, all nearest neighbors will be connected subject to feasibility constraints. With other and more complicated methods (especially heuristics), less importance may be attached to the distance between customers.

Another possible determinant of p_{ij}^{k} is the location of i and j relative to the depot. As may be observed from the savings criterion, SAV_{ij}^{k} increases as i and j become more distant from k. Thus if $p_{ij}^{k} = F(SAV_{ij}^{k})$ then, ceteris paribus, the likelihood that two nodes will be connected increases as a function of $(d_{ki} + d_{kj})$. This implies that the emphasis placed on connecting delivery points on the basis of their proximity to the depot may be an important behavioral question.

An indication of the relative importance of these two determinants of trip link probabilities is provided by some experiments with a version of the savings criterion shown below which includes a shape parameter, λ.

$$SAV_{ij}^{k} = d_{ki} + d_{kj} - \lambda d_{ij} \tag{3.35}$$

In the limit as $\lambda \to \infty$, the modified savings approach becomes the proximity method in which the links are formed solely on the basis of the distance between the deliveries. As is obvious the modified savings criterion reduces to the savings criterion for $\lambda = 1$.

Gaskell (1967), Webb (1972b), and Golden, et al. (1975) have all conducted empirical experiments with heuristics in which links were made according to one or more versions of the modified savings criterion subject to the problem constraints. Gaskell utilized a value of $\lambda = 2$. Webb (1972b,pp. 365-6) reported the following results.

> "As the weight was reduced, from the proximity criterion with weight ∞, to the savings criterion with weight = 1, the results obtained almost invariably improved. In these tests, no evidence of an optimal value of the weight greater than 1 was found. This observation would appear to contradict much popular opinion, particularly amongst practical journey planners, that distance between deliveries should be given considerable emphasis, as is implied, for example, by manual methods of planning journeys. Although it is possible that the examples and conditions chosen are not typical of those met in practice and that different results would be obtained under different conditions, published evidence to justify greater emphasis on the distance between deliveries than on the distance of deliveries from the depot appears to be lacking."

A similar finding was obtained by Golden, et al. who found that values of λ slightly greater than 1 yielded the best solution. However, both Gaskell and Golden cautioned that the optimal value of λ may vary significantly with the characteristics of the specific distribution problem and appeared to be truly problem dependent. These findings suggest that empirical estimates of λ from behavioral data might also prove to be context dependent.

A possible interpretation of these experiments is that there may be systematic effects of the interaction of transport pattern choice problem characteristics and constraints which affect the probability of internodal linkages. For example, the larger customer demands SH_i and SH_j are relative to the vehicle capacity, VC, the more likely that i will be connected to the depot and not to j. In fact, in the extreme case, if $SH_i + SH_j > VC$, node j is not even a feasible trip destination for a trip that originates at i.

Similarly, other factors which may decrease the degree of trip chaining will also increase the probability of depot-based links and decrease the probability of links among the demand points. In some cases, it is possible that nodes which are distant from the depot particularly in relation to the distant/time constraint, DTC, are more likely to be served on depot-based trips than nodes which are close to the depot and other demand points. This could possibly counteract the opposite effect of distance from depot as specified in the savings function.

It is not difficult to see that a condition for j to be a feasible trip destination for a trip which originates at i on a tour originating at k is that $d_{jk}+d_{ij}+d_{ki}<DTC$. However, in most cases, both this constraint and other distant/time constraints on overall transport patterns are less likely to impact trip linkages than vehicle capacity limitations which apply to individual vehicle tours.

In considering the factors that might influence the choice of a nodal alternative from the set of alternatives, only brief mention has been made of the point that certain restrictions might limit the possibilities. The alternatives for trip linkages will now be examined more closely.

Under the assumptions given previously, in any transport pattern choice each non-depot node will be linked to two other nodes, one of which might be the depot. The number of trip connections to the depot will be twice the number of tours, so that if the tour frequency is greater than 1, the depot will be an alternative trip destination for more than one trip origin.

A more precise characterization of the alternatives for trip connections is given below. If the number of consignments in a single transport pattern shipped to zone i from the depot D in zone k (denoted alternative k_D) is S_i^k, and the number of tours generated in zone k is M^k, then the number of alternative trip destinations in zone j for a trip which originates in zone i, N_{ij}, is given as follows:

$$N_{ij} = \begin{cases} S_j^k & \forall i;\ \forall j \neq i,\ k_D,\ k_{\bar{D}} \\ S_j^k & i \neq k_{\bar{D}},\ j = k_{\bar{D}} \\ S_j^k - 1 & \forall\ j=i;\ i,j \neq k_D \\ 0 & j = i = k_D \\ M^k & \forall i \neq k_D,\ j = k_D \end{cases} \tag{3.36}$$

where $k_{\bar{D}}$ is the set of non-depot nodes in zone k. If N_{ij} is zero (or negative), j is not a feasible trip destination for a trip which originates in zone i. It may readily be seen that these expressions are consistent with a logical restriction on trips (i.e., that the same trip cannot terminate at the node at which it originates). Conventional aggregate gravity models do not take account of this restriction and the failure to do so could result in bias, particularly when the number of zonal trip destinations is small or there is a high incidence of depot-based trips.

An important characteristic of trip destination choice is implicit in the formulation of the firm's spatial choice problem in a manner which restricts the set of trip destination alternatives to its depot and the nodes (or zones) representing the firm's customer demands. Only nodes served on tours originating at the same depot node are feasible alternatives for trip linking.

Since even similar firms in the same industry typically serve disparate sets of customers (particularly during small intervals of time) from different depots, different firms may share few if any common alternatives. This suggests that unless we explicitly account for cross-sectional variation in the alternatives faced by different firms it will not be possible to perform an accurate quantitative assessment of the determinants of trip distribution or to test hypotheses about the consequences of the firms' routing and scheduling behavior. In contrast, conventional aggregate gravity models (GM) explicitly assume identical and broader choice sets, and this assumption is likely to result in biased parameter estimates and behaviorally unrealistic predictions. In the traditional aggregate trip distribution models formulated for all goods vehicle trips or for goods vehicle trips produced by a given industry, it is implicitly assumed that all trip linking choices (i.e., those with non-zero trip generation) are feasible and are equiprobable subject to the familiar GM constraints. Even if only aggregate data were available making it impossible to distinguish each firm's choice set, we would still logically require that only destinations receiving goods from the same tour origin (for pure delivery tours) and the depot itself could be potentially feasible trip destinations. Therefore, these aggregate specifications are fundamentally incorrect.

Unfortunately, the disaggregate conceptualization of trip destination choices presented above does not generalize to an improved aggregate formulation because aggregate choice set characterizations will not correspond to disaggregate choice sets unless all firms face identical sets of alternatives. To see this, consider the simple example shown in Figure 3.3-9 of the 1-tour transport patterns chosen by two firms q_1 and q_2, located in zone k. The choice sets for the firms are $L_{q_1} = (k,i,j,l)$ and $L_{q_2} = (k,i,j,m)$, respectively. However, if only aggregate data were available (i.e., we could not distinguish the firms), the aggregate choice set we would infer, $L = (k,i,j,l,m)$, would include the tour origin and all the shipment destination zones. This suggests that the probability of a trip link (the dotted line in Figure 3.3-9) connecting zones l and m would be greater than zero. This is a behavioral impossibility in the disaggregate modelling context and is likely to lead to biased probabilities from the aggregate model for all other potential trip links as well.[32] Moreover, it would seem that with increasing degrees of aggregation, the discrepancy between the actual disaggregate choice sets and the corresponding aggregate choice sets is likely to grow.

The logical conclusion of this argument is that the most accurate representation is provided by the disaggregate model specification of the alternatives, and all the more

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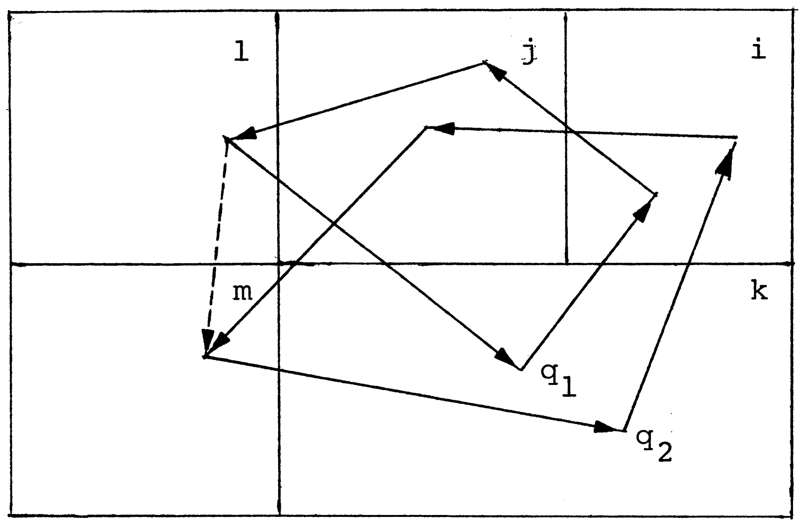
[32]Including an attractive alternative which appears desirable but is actually infeasible leads to biased predictions (Ben Akiva, 1973, p. 116).

Figure 3.3-9

An Illustration of Trip Destination Choice Sets



aggregate versions are likely to suffer from some (probably an indeterminate) degree of aggregation bias. Ideally, one should estimate a disaggregate model and then perform the necessary aggregation to obtain the desired quantities.

A problem common to both aggregate and disaggregate models of trip linking and many other decisions is that we generally do not know which alternatives are actually considered, but not chosen even under all the simplifications required to make the trip distribution problem tractable. At present, one reasonable choice set rule for empirical work is that all of the nodal alternatives in chosen transport patterns are or may be considered, and this, of course, need not be the case. Further work, including data gathering on routing and scheduling behavior, may be needed to shed light on this question.

The preceding discussion suggests that a wide variety of factors could potentially influence goods vehicle origin-destination patterns at the micro level. A priori considerations suggest that location with respect to the depot, consignment size, vehicle characteristics, work rules, and routing and scheduling methods employed might be significant determinants of trip linkages. Unfortunately data appear to be unavailable for a comprehensive test of these hypotheses and this might be kept in mind when future data collection efforts are planned. Simulation experiments may also provide a fruitful avenue for future research.

3.4 Conclusion

The picture that emerges from this examination of urban freight transport behavior is one of great complexity with respect to the context, character, and outcomes of firms' transport pattern choices. Decisions influencing the transport of consignments and the routing of goods vehicles are intimately related to longer-term decisions firms make about location, production, consumption, and distribution logistics. Moreover, firms' transport pattern decisions fundamentally depend on decisions made by other entities with whom they trade.

Consideration of the determinants of transport pattern choices suggests that these decisions are sensitive to a wide range of factors which have generally been excluded from empirical studies and planning models. Logistical arrangements, vehicle supply, consignment characteristics, delivery costs, transport level of service, and a wide variety of constraints were among the factors hypothesized to be determinants of urban freight transport behavior.

An important conclusion of the analysis is that transport pattern choices typically result in the selection of goods vehicle trip patterns which have a significant degree of trip chaining. It appears that trip chaining makes it possible to increase consignment frequencies, reduce delivery costs, and possibly improve transport level of service. Trip chaining illustrates one aspect of the inherent complexity of transport pattern choices which is that these are joint decisions about groups of consignments, groups of goods vehicle trips, and their attributes. Consequently, it is clear, on conceptual grounds, that decisions regarding individual goods vehicle trips are not independent of decisions about other goods vehicle trips.

Although the complexity of transport pattern choices poses a considerable obstacle to their analysis, it is, nevertheless, possible to hypothesize relationships among the attributes of a transport pattern choice and to relate these attributes to the firm's decision context. These tasks are greatly facilitated by the proposed paradigm of vehicle routing behavior.

The paradigm of firm behavior suggests a variety of hypotheses and conclusions concerning the characteristics of transport pattern choices. An important conclusion is that trip generation is an aggregate of two quantities--(1) the number of trips made for pickup and delivery which is equal to the consignment frequency under the assumptions of the theoretical analysis and (2) the tour frequency. Therefore, the determinants of goods vehicle trip generation are hypothesized to be the determinants of consignment and tour frequencies. The tour frequency is, in turn, seen to be a simple function of the consignment frequency and the degree of trip chaining. These findings indicate that from the perspective of the transport provider there is a very well-defined relationship between the generation of consignments and goods vehicle trips.

Because it reduces the distance travelled and the time required to make deliveries, trip chaining is hypothesized to be a significant determinant of consignment frequency as well as urban delivery costs. The linkage of trips in multi-destination tours is an important means of achieving economies of scale in urban freight distribution.

Vehicle routing behavior also appears to have systematic effects upon spatial patterns of goods vehicle trips. In addition to the distance/travel time to alternative destinations, the distance from the depot and constraints on vehicle capacity and tour duration are hypothesized to influence goods vehicle origin-destination patterns.

An overall conclusion of the theoretical analysis is that trip chaining exerts a powerful influence upon all the important aspects of goods vehicle tripmaking with urban areas considered in this chapter. This suggests that because they ignore trip chaining, traditional methods of modelling goods vehicle trip generation and distribution may be biased and of questionable validity. It also suggests that reformulation of models of urban goods vehicle traffic may be needed to account for the impacts and determinants of urban freight transport behavior.

The theoretical analysis raised many questions concerning the significance and magnitude of the determinants of urban goods vehicle traffic which can only be addressed with empirical data. The hypotheses discussed in this chapter also have strong implications for the structure and content of an empirical analysis of the relationship between goods transport and urban spatial structure. The next chapter describes the approach taken in the empirical analysis and hypothesis testing conducted in the course of this research.

Appendix

The Number of Transport Pattern Alternatives

This appendix presents a calculation of the number of alternatives for a vehicle routing problem of fixed size. In the computation, it is assumed that the constraints have limited the maximum number of consignments that are to be considered for delivery to n.

We begin by examining all of the alternative routings with which the firm can deliver precisely n consignments from a single depot. Figure 3A-1 depicts the alternatives for n=3 by illustrating the different ways consignments j, k, l can be delivered from depot D under the assumption that constraints of vehicle size or tour length are not binding. Each path in the figure shows one of the 24 alternative orderings of tours and their component trips.[33]

We now seek an expression for the number of alternatives, N_n, that exist to serve precisely n customers from a single depot. Upon inspection, it can be seen that the number of alternatives, N_3, for n=3 can be expressed as

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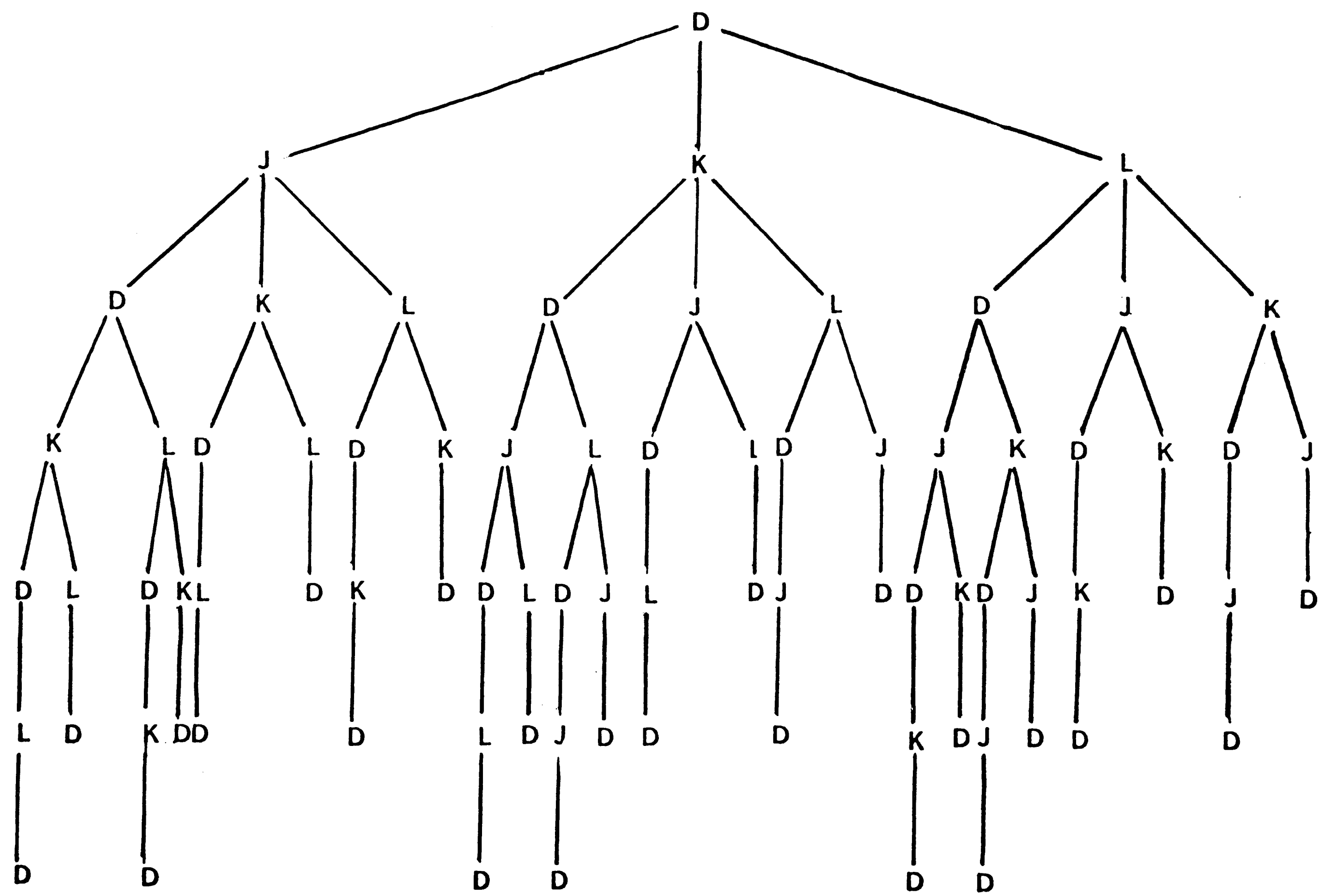
[33]If only combinations rather permutations of tours are counted, there are 13 distinct patterns.

Figure 3A-1

Transport Pattern Alternatives for the Case of Three Customers



a multiple of the number of alternatives for n=2, N_2, and that N_4 can be expressed as a multiple of N_3 following the diagrams in Figure 3A-2. Specifically, the pattern implies, at least for N_2, N_3, and N_4, that $N_n=2nN_{n-1}$.

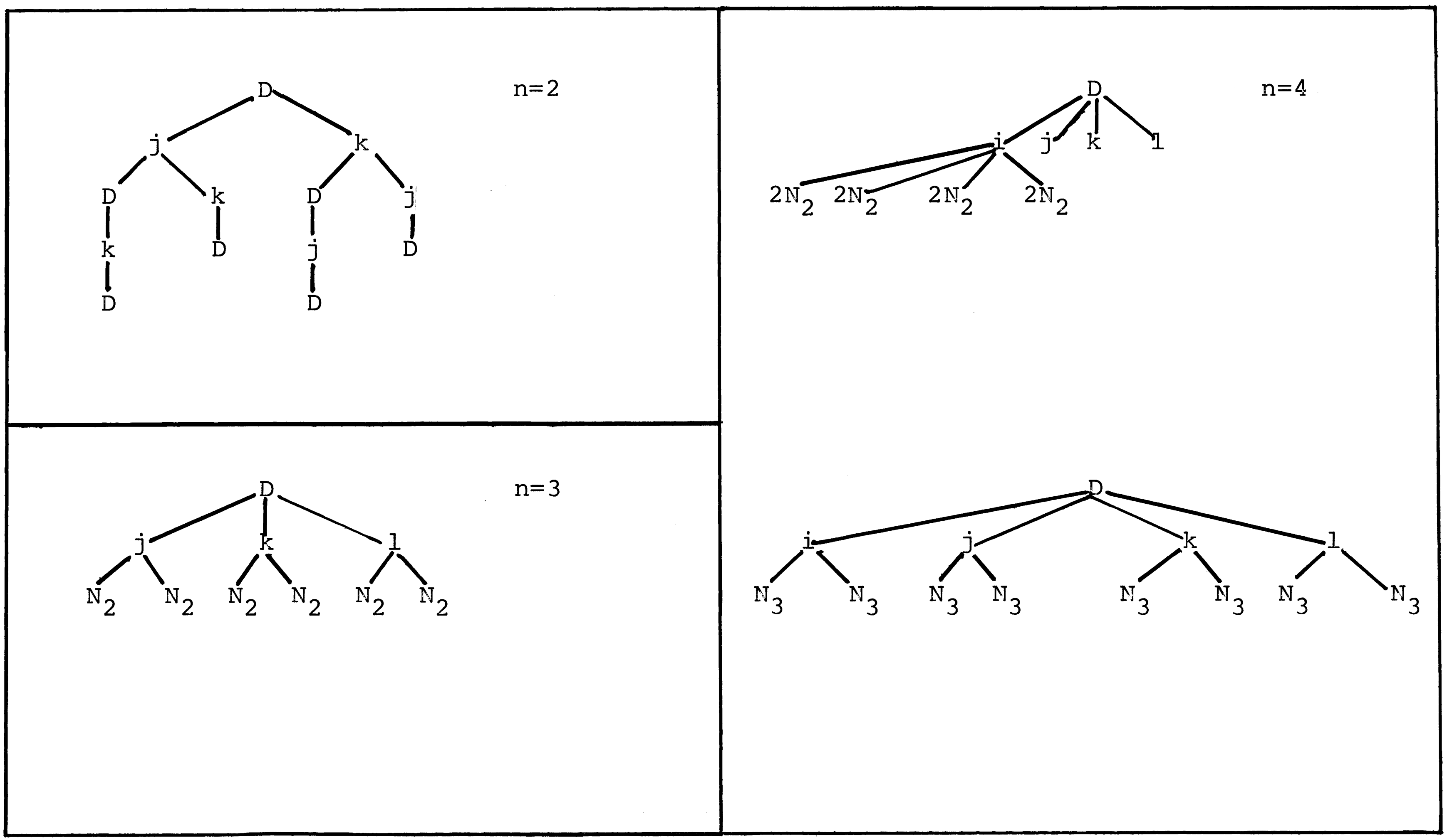
The proof for all n follows inductively. In the case with n+1 nodes, there are n+1 branches. Each of these n+1 branches also has n+1 branches -- the n remaining destinations and the depot. Because the number of branches from the depot is n, there are N_n alternatives passing through that node. The number of alternatives which pass through the remaining n destinations is, of course, also N_n. Therefore, we can write $N_{n+1} = (n+1)2N_n$, which holds for n+1 if it holds for n. Since the expression is valid for n=2 and n=3, it follows that it holds for all n.

An explicit expression for N_n in terms of n can be obtained by the sequential substitution of $N_{n-j}=2(n-j)N_{n-j-1}$ for N_{n-j} in the above expression for j=1, n-1. Proceeding thusly, $N_n=2^{n-1}\,n!$ is obtained. Therefore, there are precisely $2^{n-1}n!$ ways in the firm can serve exactly n customers from a single depot.

To compute the total number of the firm's transport pattern alternatives, T_n, it is necessary to recognize that the firm's alternatives also include the choices associated

Figure 3A-2

Alternatives for 2,3, and 4 Destinations



with serving 0, 1, 2,..., k,..., n customers. Since there are $n!/(n-k)!k!$ different combinations of k customers, there are $n!/(n-k)!k!N_k$ ways of serving k customers. Therefore,

$$T_n = C_0^n + C_1^n N_1 + \ldots + C_k^n N_k + \ldots + C_n^n N_n$$

where $C_k^n = n!/(n-k)!k!$

The vast number of transport pattern alternatives for the smallest distribution problems is indicated in Table 3.2-3 in the main body of the chapter, which provides a tabulation of T_n for n=1, 10.

Chapter 4 Analytical Approach

This chapter describes the approach taken in this research to the empirical analysis of the determinants of urban goods vehicle trips. First, in 4.1, the general framework to be used in quantifying the relationship between goods transport and urban spatial structure is described. The second part of the chapter, 4.2, provides an account of the substantial data problems encountered in implementing this framework. Data limitations were found to place significant restrictions upon the choice of the empirical approach.

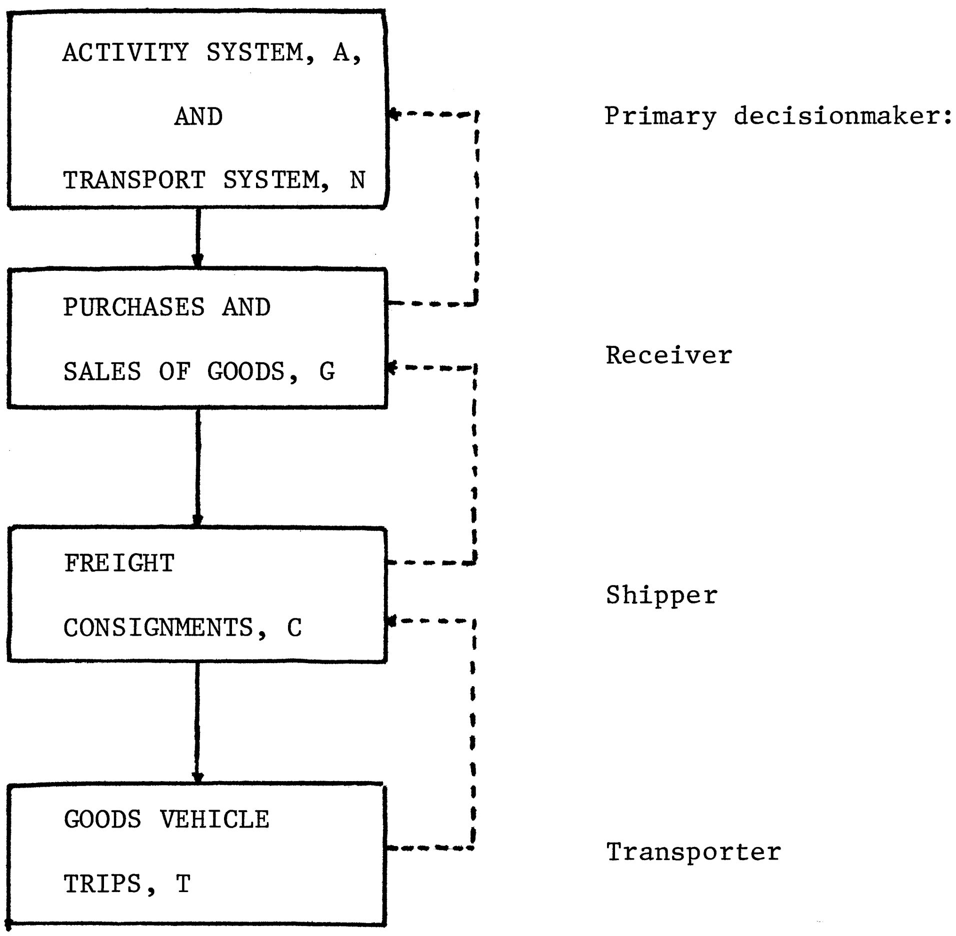
Two separate empirical analyses which in concert could achieve the stated research objectives were found to be feasible. The first entailed the use of aggregate cross-sectional models to analyze the generation and attraction of trips, tours, and consignments, as functions of each other, activity measures, and characteristics of the transport system. The second entailed empirical analysis of the spatial distribution of trips within individual truck transport patterns. The approach taken in these analyses is discussed in 4.3 which provides an overview of the empirical research that was undertaken.

4.1 Modelling Framework and Approach

The demand for urban goods vehicle trips is derived from the demand for the goods and services produced, consumed, and exchanged within urban areas. In the proposed paradigm of firm behavior, short-run transport pattern choices were examined in the context in which the firm's daily shipment pattern was given. In order to relate the flows of goods vehicle trips to urban spatial structure, it is necessary to place the theory of short-run transport pattern choices within a broader framework in which consignments and trade flows are related to the location, intensity, and mix of socio-economic activities and the supply of transport.

Consistent with prior reasoning, the overall relationship between goods transport and urban spatial structure will be viewed in terms of the model structure shown in Figure 4.1-1 in which the frequency and spatial pattern of consignments and goods vehicle trips are dependent upon the demand for goods. The behavioral justification for this structure is that decisions which govern intraurban trade typically precede decisions about freight shipments and goods transport. Moreover, the latter decisions are typically made by the providers of goods or the providers of transport rather than the consumers of

Figure 4.1-1 The General Structure of the Relationship between Goods Transport and Urban Spatial Structure



goods, although there will be instances in which these will be the same behavioral entities.

Because of the close relationship between trips and consignments and because of the fact that the most common logistical arrangement in urban goods transport is one in which the transporter and the shipper are the same firm, there may be less justification for separating consignments and trips in a framework for quantitative analysis. Basically, this is equivalent to assuming a hierarchical decision structure for the shipper-transporter. This particular simplification may, in actuality, be employed by many firms (Webb, 1972a) and, therefore, be justified on behavioral grounds.

The dashed arrows in Figure 4.1-1 indicate feedbacks representing the effects of lower order decisions upon higher order decisions. In the short-run, changes in the provision of goods transport may induce shifts in consignment patterns or changes in transport arrangements or consignment characteristics may cause changes in urban trade. In the long-run, changes in the patterns of purchases and sales of goods may induce shifts in the intensity and location of activities.

There are, of course, many difficult and unresolved questions concerning the existence and nature of equilibria in the activity/transport system. However, we shall assume for the purposes of this research that A and N are determined exogenously. It is necessary to point out that this assumption may be hard to justify for freight transport because of the private provision of goods and goods transport and that this may pose a formidable barrier to successful forecasting. Since the objective here is to explain data for only one point in time rather than prediction for some future point in time, this simplification will hopefully be of lesser adverse consequence.

The framework depicted in Figure 4.1-1 may be represented by the recursive model structure below.

$$G = D_1 (A, N) \qquad (4.1)$$

$$C = D_2 (G, A, N) \qquad (4.2)$$

$$T = D_3 (C, G, A, N) \qquad (4.3)$$

where D_1, D_2, and D_3 are "demand" functions and the variables (defined in the figure) represent multidimensional arrays. Among the attributes of G, C, and T of potential interest are the traditional ones of generation, attraction, and spatial orientation (O-D) as well as such other characteristics as consignment sizes and tour frequencies.

The methodological approach chosen for the empirical study was the estimation of econometric (or statistical) models of the relationship between goods vehicle trips and the activity/transport system. This methodology requires precise specification of the model relationships to be estimated.

A variety of alternative conceptualizations are possible within the framework described by equations 4.1-4.3. One basic modelling choice is that between aggregate and disaggregate approaches. Other obvious issues in the formulation of an analytic approach include the articulation of the structure of each equation block, the specification of the dependent and independent variables and the choice of functional forms for each equation to be estimated.

The most straightforward analytical approach would be that of disaggregate analysis of these relationships at the firm level. This approach not only corresponds most directly to the theory that has been developed, but also has a number of advantages which typically make disaggregate analysis preferable to aggregate analysis (for example at the zonal/industry level) when disaggregate data are available. Generally speaking, if disaggregate data were available, either disaggregate or aggregate analysis would be feasible, but disaggregate analysis would be strictly preferable on grounds of statistical efficiency. There are, however, possible exceptions to this generalization. For example, if the aggregate data is measured more accurately than the disaggregate data or if the aggregate models have better specifications, aggregate analysis could well be superior to disaggregate analysis (Maddala, 1977).

Aggregate analysis has the limitation that, absent highly restrictive conditions, inferences cannot be made about disaggregate behavior from aggregate models. Further, because aggregate models can only account for between group variance, considerable information loss may result (Fleet and Robertson, 1968; McCarthy, 1969).

Generally speaking, there are probably few instances in urban transport demand analysis in which aggregate models will have better specifications than disaggregate models. Consequently, disaggregate analysis (with aggregate predictions made after model estimation) would be the better procedure if disaggregate data were available. However, appropriate disaggregate data did not (and still do not) exist for analysis of urban goods transport. This, and other data problems, to which we now turn, presented a considerable obstacle to be dealt with in developing an empirical strategy.

4.2 The Problem of Data

The preceding chapters provide the basis for understanding the substantial quantity of data which would be required in order to provide a test of the theory that has been proposed and to quantify the relationships which link the transport of goods to the location, intensity and mix of activities within a metropolitan region. Broadly speaking, disaggregate data would be required describing the activity system, the supply of transport, goods purchases and sales, the context for and character of transport decisions, flows of consignments and the generation, attraction, and spatial distribution of goods vehicle trips. The requirements for data falling in these categories will be described briefly.

A characterization of the activity system appropriate for analyzing urban freight transport would have to include a description of the population of firms (establishments) and their characteristics. At a minimum it would be necessary to be able to classify firms in terms of the products they produce, distribute, or transport and to measure the firm characteristics which may be determinants of urban goods vehicle trips.

Necessary data on the supply of transport would include transport network characteristics, terminal and parking supply, and the characteristics of firms' vehicle fleets and operations. Because of their different operating characteristics and because they are subject to special traffic restrictions, goods vehicles do not face the same network links and link travel times as cars. Ideally, separate networks (perhaps even for different types of goods vehicles) would be coded for peak and off-peak periods.

Terminal and parking capacity, availability and duration are other potentially important aspects of goods transport supply. These attributes will probably vary by location, time-of-day, and the destination activity/landuse characteristics (Keefer, 1963). It would also be desirable to have data on the temporal duration of the other activities described previously which are required as part of delivery operations such as planned idle time and the time required for loading and unloading goods vehicles.

Clearly, the supply of goods vehicles of different types owned, leased, and/operated by each establishment is an important determinant of the provision of urban freight transport. In addition to the transport provided by firms on their own account, the availability, costs, and level of service characteristics of for-hire urban transport services are obviously also a component of urban freight transport supply.

Data necessary to describe the context and character of urban freight transport decisions can be inferred from the discussion of the firm's transport pattern choice process and utility function given in Section 3. Foremost among the data requirements would be measurement of the volume and spatial distribution of goods purchases and sales. This information provides the link to the activity system and a means of explaining where trips actually take place. Ideally, this data would include descriptions of the commodity composition of purchases and sales, the timing and size of orders, price and payment methods, and relevant delivery deadlines or other level-of-service requirements.

The final set of required data to explain goods transport decisions would be the actual consignments and goods vehicle trip patterns chosen by firms. Appropriate measurement dimensions would include numbers, volumes, timing, and location of goods collections, deliveries and vehicle trips. It would also be important to measure the somewhat more covert aspects of transport pattern decisions such as level of service in terms of delivery times and reliability. A particular requirement of a disaggregate analytical approach employing discrete choice models is for data on the subset of alternatives considered but not chosen by firms for various choice problems. Data of this type do not exist and probably could only be obtained by in-depth interviewing.

The preceding overview of data requirements may be contrasted with the data which was available or thought to be obtainable during the course of this research. Alternative data sources considered included existing data sets, special data collection efforts, and simulation.

The richest existing sets of data on urban goods transport were (and are still) to be found in the large-scale metropolitan transportation studies of the type which were common in the U.S. in the 1960's. Prescriptive guidance for many of these studies offered by FHWA (1973) was that a random sample of goods vehicles be selected and their daily movement in time and space recorded for a specific sample day. As a result, this procedure provides a large number of observations of actual goods vehicle transport patterns and the spatial arrangement of their component tours and trips. Unfortunately, the data obtained in this way is not the desired form of disaggregate data, because the firms owning or operating the vehicles were not identified nor were their characteristics surveyed. There is no way of knowing whether these vehicles were part of multiple vehicle fleets, for example. However, sufficient data on the activity system and the transport network were always collected as part of these studies so as to make aggregate analysis of goods vehicle trips a possibility at the industry level.

A limitation of the origin-destination surveys was that they were not designed with the view of measuring freight flows or spatial patterns of consignments transported. However, many studies, including the Boston travel survey whose data were used in the empirical work presented here, did include information about the commodity carried, the number of consignments delivered per trip and other pertinent data which might be used in empirical analysis. The data collected in the goods vehicle survey were also judged to be of considerable value in the empirical analysis of individual truck transport patterns.

A special primary data collection effort and the use of simulation were the other sources of data considered for the empirical analysis. Although simulation appeared to be an attractive method of generating hypothetical data on firms' vehicle routing and scheduling decisions given input data on customer demands, it was decidedly less attractive than the alternative data sources because of its well-known limitations (Wagner, 1970) and its inconsistency with the major research objective of explaining actual goods vehicle traffic patterns.

The major advantage of collecting data specifically for this research was that it was the only way of obtaining disaggregate data on firm characteristics and freight transport behavior. As indicated in the literature review, small disaggregate data collection efforts had proven to be feasible although difficulties had been encountered in persuading firms to expend the time required and to provide information they thought to be of a confidential nature (Watson, 1975). However, none of the prior disaggregate surveys with which the author was familiar had sought detailed information of the scope and depth that would be required here. In particular, none of these studies had collected data on freight transport decisions making it problematical to judge how difficult this might prove to be. It was thought, however, that it would be feasible to obtain driver and dispatcher logs so that vehicle patterns and shipments transported could be recorded. Of course, it would also be necessary to include some means of obtaining detailed information concerning the characteristics of the transport network at the time of data collection. Although it was also thought to be feasible, it was recognized that there might be some difficulty in gathering data for enough firms of similar type to estimate disaggregate models for one industry.

A major objective of this research was to provide a quantitative explanation of the level and location of goods vehicle traffic as a function of the spatial pattern intensity, and mix of activities. To be able to account for the location and intensity of goods vehicle trips at non-depot sites and not just the level of traffic produced by one group of firms, a prohibitively large survey effort would be required. Thus the major disadvantage of a feasible scale disaggregate approach involving a special data collection effort was that it would fail to achieve a primary research objective.

A final consideration was the view that any data collection efforts would be premature until at least minimal attempts were made to perform hypothesis testing and to analyze existing data from the theoretical perspective taken here. It was hoped that at least one of the consequences of the empirical work performed in this research would be the generation of guidance with respect to data requirements to support further research. For these reasons, it was decided to formulate an empirical approach which could be implemented with an existing data set on goods vehicle trips and the activity/transport system which had been collected as part of one of the large scale metropolitan transport studies.

Several alternative data sources were investigated, and data pertaining to the Boston (Massachusetts) metropolitan region were selected for the empirical study. As will be discussed in greater detail subsequently, the region was the subject of a major regional planning study with a full complement of analyses, a detailed and extensive transportation inventory, and supporting research on land use models, resulting in the availability of a wide variety of socio-economic and transport data. The complexity and diversity of the region and the interdependence of its subareas was a positive factor; it was thought to offer a good opportunity to examine urban freight transport demand in a variety of settings and to test hypotheses concerning locational variation in levels of goods vehicle traffic. A predominant consideration was the detailed information which had been collected on daily truck transport patterns including such measures as the number of consignments delivered per trip and per day and the commodities transported. Lastly, the choice was also influenced by the author's familiarity with the region and the potential integration of research findings with ongoing or proposed research efforts on industrial location and the input-output structure of the region.

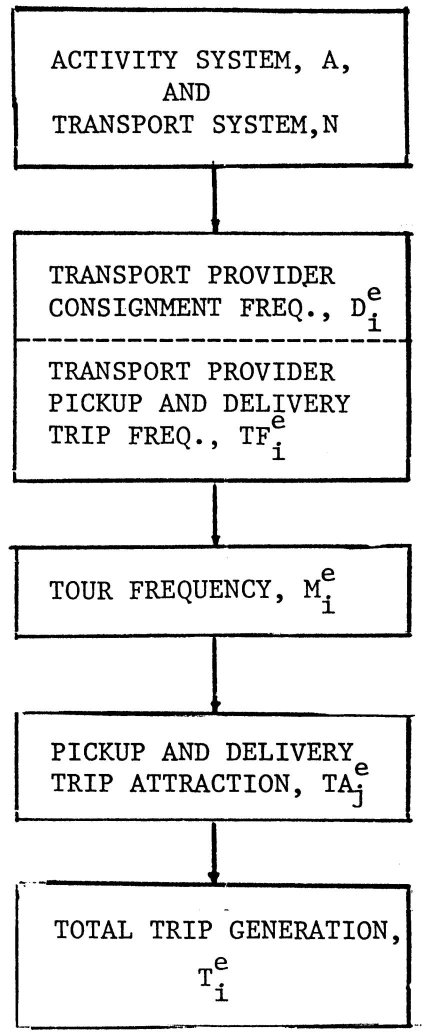
4.3 Empirical Research Strategy and Overview

A two-stage approach was taken in the analysis of the relationship between the transport of goods and the spatial structure of the Boston metropolitan region. The first stage consisted of an aggregate analysis of the components of goods vehicle trip generation for trips made by manufacturing, local for-hire transport, wholesale and retail trade, and all activities combined. The second stage consisted of an exploratory empirical analysis of the spatial distribution of trips within vehicle trip patterns for vehicles operated by food manufacturers. The approach taken in each stage of the empirical analysis will now be described in greater detail.

4.3.1 Aggregate Analysis of the Relationship between Goods Transport and Urban Spatial Structure

The aggregate analysis of the components of goods vehicle trip generation consisted of implementation of the modelling framework described in 4.1 and specified in greater detail in Figure 4.3-1 through a series of cross-section regression models. As indicated in the figure, the

Figure 4.3-1 The Structure of the Aggregate Trip Generation Modelling Framework



attributes of intraurban goods transport included in the empirical analysis were the frequencies of transport provider pickup and delivery trips, consignments, and tours; pickup and delivery trip attraction; and total trip generation by traffic zone. The absence of data on goods purchases and sales made it impossible to estimate structural equations relating these quantities to the activity/transport system or structural equations relating consignment and trip frequencies to goods purchases and sales. Instead reduced form equations relating transport provider consignment and trip frequencies to the activity/transport system were estimated.

In the modelling framework, activity levels, transport network characteristics, vehicle fleet characteristics, and trip chaining are considered to be fixed, predetermined variables. Based on the arguments made previously, the degree of trip and delivery chaining are considered to be determined by exogenous factors such as vehicle capacity, customer demands, and other predetermined variables many of which are noted above.

The structural equations and definitions of the variables for the proposed model system for the trip generation of an industry (denoted e) are given in Table 4.3-1. The system consists of two equations to be estimated

Table 4.3-1 The Goods Vehicle Trip Generation Model System

1a. $D_i^e = h_1^e(A,N)$

or

1b. $TF_i^e = h_2^e(A,N)$

2a. $M_i^e = D_i^e / DCH_i^e$ or 2b. $M_i^e = TF_i^e / TCH_i^e$

3. $TA_j^e = h_3^e(\Sigma TF_k^e, A, N)$

4. $T_i^e = M_i^e + TA_i^e$

where D_i^e = the delivery frequency of industry e in zone i

TF_i^e = the pickup and delivery trip frequency of industry e in zone i

M_i^e = the tour frequency of industry e in zone i

TA_j^e = pickup and delivery trip attraction in zone j

T_i^e = total goods vehicle trips generated by industry e in zone i

DCH_i^e = the average number of deliveries per tour for industry e in zone i

TCH_i^e = the average number of pickup and delivery trips per tour for industry e in zone i

A = an array of activity system variables

N = an array of transport system variables

(1a or 1b, and 3) and two identities (2a or b and 4). Since the objective is to explain trips, equation 1a could be omitted if equation 2b and not 3a is used to estimate tour frequency. However, since consignment frequency is of interest in its own right, equation 1a has been included in the equation system.

As reflected in the definitions of the dependent variables, the formulation of the model system has been designed to deal with the presence of mixed logistical arrangements in urban goods transport. Under the simplifying assumption of pure delivery logistical systems, the dependent variables in the model system have the following interpretation. D_i^e is the number of consignments of the output of industry e in zone i transported to all receivers in all zones. TF_i^e is the number of trips to customer locations made in the course of delivering consignments of industry e's output from zone i to all customers. M_i^e is the number of delivery tours, and TA_j^e is the number of goods vehicle trips in zone j on which deliveries of industry e's goods are made from all intraregional sources.

In the case of pure collection logistics systems, parallel but differing definitions apply. D_i^e becomes the number of consignments collected by industry e in zone i from all sources, and TF_i^e is the number of goods vehicle trips made in all zones for the purpose of collecting the aforementioned consignments. M_i^e is the number of collection tours and TA_j^e is the number of trips generated in zone j on which industry e collects consignments.

Because mixed pick-up and delivery operations exist and because the survey data did not unambiguously identify the origin and destination of each consignment, it is necessary in the empirical analysis to aggregate and to estimate equations based on the composite variables defined in Table 4.3-1. For this reason, the following definitions of the dependent variables are offered for the case of mixed logistical arrangements. D_i^e is the frequency of consignments delivered to other locations and collected from other locations by industry e in zone i. TF_i^e is the number of trips made for the purpose of collecting and delivery these consignments. By definition, TF_i^e does not include one trip per tour which is assumed to be determined by the tour frequency and is not made for the purpose of a consignment collection or delivery.[1] Under mixed logistical arrangements, M_i^e is the frequency of tours of all types and TA_j^e is the number of industry trips attracted to zone j for collecting, delivering, or both collecting and delivering

[1]Strictly speaking, this is an approximation which applies exactly when consignments are not collected and dropped off on the same trips.

consignments. It is important to recognize that while these definitions facilitate a workable approach for empirical analysis, an obvious way to improve the modelling system and the analysis of urban goods transport would be to treat the issue of logistical arrangements explicitly in the modelling framework.

After a description of the setting for the empirical research in Chapter 5, the quantitative analysis of the relationship between intraurban goods transport and the spatial structure of the Boston metropolitan region conducted through the estimation of the model system is presented in Chapter 6. The chapter begins in section 6.1 with a presentation of statistics describing the characteristics of goods vehicle traffic within the study area. In section 6.2, a description of the hypotheses concerning the determinants of goods vehicle trip generation is provided in terms of the model system described in Table 4.3-1. These hypotheses are used to develop the detailed specifications of the econometric models which are estimated.

Delivery and trip frequency are hypothesized to be determined by employment in the activity providing the transport, the number and size of vehicles operated, consignment sizes, the location and accessibility of the transporter, and the degree of delivery or trip chaining. By virtue of the model structure adopted (see equations 2a and 2b), these factors are also hypothesized to be the determinants of tour frequencies.

Consistent with the theoretical view that it is the decisions of transport providers which, based on the demand for goods, determine the overall level of goods vehicle traffic, the number of trips attracted to all non-depot locations is a function of (and must be consistent with) the total level of pickup and delivery trips as given by equation 1b. The level of trips attracted to each zone is hypothesized to be a function of its location, accessibility, intensity, and mix of activities and the distribution of consignment sizes.

The total number of trips generated by a transport provider in a zone is the sum of the tour frequency and the number of pickup and delivery trips attracted. As indicated in equation 4, total trip generation is determined by an identity and not by an equation to be estimated.

This analytical approach has a number of features which are thought to represent considerable improvements over approaches taken in prior empirical work. One important characteristic of the approach is that trip generation is directly related to the characteristics and activity of transport providers. Theory suggests that decisions made by transport providers exert considerable influence over the level and spatial distribution of goods vehicle traffic. This formulation also facilitates model specification and leads to a more logical and meaningful grouping of trips for empirical analysis.

A second notable feature of the analytical approach is that it explicitly takes account of the phenomenon of trip chaining which is hypothesized to be an especially important characteristic and determinant of urban goods vehicle traffic. Trip chaining also dramatically influences the relationship between the transport of goods and urban spatial structure because it results in an high incidence of trips connecting non-depot goods demand and supply points served by the same transport provider. Moreover, as was discussed in Chapter 2, the failure to take account of trip chaining has typically led to inconsistencies in the measurement and analysis of consignment and trip generation.

A third improvement results from taking account of the structure of the constituent relationships which together determine total zonal trip generation. This reduces aggregation bias and permits improved model specification.

The empirical results of model estimation for the different industry groups and total activities are presented in section 6.3. The industry is arguably the appropriate unit of analysis because similar activities are thought to exhibit similar goods transport demands and behavior and to be influenced by similar exogenous factors. Separate equations were estimated for manufacturing, local for-hire transport, and wholesale and retail trade. Total activity models were also estimated, in part, for purposes of comparison with the industry models.

Outputs of the empirical analysis include elasticities of delivery, trip, and tour frequency, trip attraction and trip generation with respect to activity and transport system variables. These provide a common set of measurements from which the major determinants of urban goods vehicle traffic can be assessed.

4.3.2 Empirical Analysis of the Spatial Distribution of Vehicle Trips

An important consequence of the paradigm of firm behavior proposed in Chapter 3 were hypotheses concerning the existence and character of systematic relationships in the spatial arrangement of trips within daily transport patterns. Because the spatial distribution of goods vehicle trips is an important aspect of the relationship between the transport of goods and the spatial structure of urban areas, it was thought to be essential to perform empirical tests of these hypotheses.

The major obstacle to the performance of a suitable empirical investigation was the absence of disaggregate data on firms' transport patterns. Because of the potentially serious theoretical deficiencies associated with aggregate models of goods vehicle trip distribution cited in Chapter 3, recourse to aggregate analysis was not thought appropriate. It was recognized, however, that a form of disaggregate analysis employing available data on vehicle trip patterns in place of data on firms' transport patterns was a feasible and valid statistical approach. This approach is described in Chapter 7 which presents the methodology adopted for the investigation of vehicle trip patterns and the findings obtained.

In order to test hypotheses concerning the determinants of trip destination probabilities, a multivariate statistical model for discrete responses (choices) is needed. The first part of Chapter 7 describes the modelling approach which employs the multinomial logit model to test alternative explanations for trip origin-destination patterns.

The data for this empirical analysis were trip patterns of goods vehicles operated by food manufacturers within a fairly large subarea of the region. The data were chosen according to criteria (described in 7.1.2) which were thought to minimize extraneous variation in vehicle trip patterns. Resource constraints limited the empirical analysis to data for just one industry; consequently, no claim is made for the applicability of the results beyond the data analyzed.

The second part of Chapter 7 provides a discussion of hypotheses regarding the determinants of trip destination probabilities in terms of alternative multinomial logit model specifications. Because of data limitations, the hypotheses tested are confined to travel time and various savings criteria probability functions. However, it is also possible to test the hypothesis that different factors influence the choice of depot destinations. The findings that emerged from the trip distribution modelling effort are discussed in 7.3 which concludes the presentation of the empirical work conducted in the course of this research.

Chapter 5 The Empirical Setting

The Boston metropolitan region was the setting for the empirical analysis conducted in this study of the relationship between the transport of goods and urban spatial structure. The data that have been analyzed were collected during 1963 and 1964 as part of the Eastern Massachusetts Regional Planning project, a comprehensive transport and land-use planning and development study.[1]

The first part of this chapter presents a description of the region and its spatial structure at the time of data collection. The scale and complexity of the study area necessarily restricts this discussion to a limited number of points of particular relevance to a study of urban goods transport. The second part of the chapter is devoted to a description of the transport and activity system data that were available for the empirical analysis.

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[1]The Eastern Massachusetts Regional Planning Project was a quasi-government activity supported by the U.S. Department of Housing and Urban Development and the Bureau of Public Roads. The project was sponsored by the Massachusetts Department of Commerce and Development and the Department of Public Works, and a variety of studies were conducted by a large number of state and local agencies and consulting firms. The documentation for relevant studies will be referenced individually.

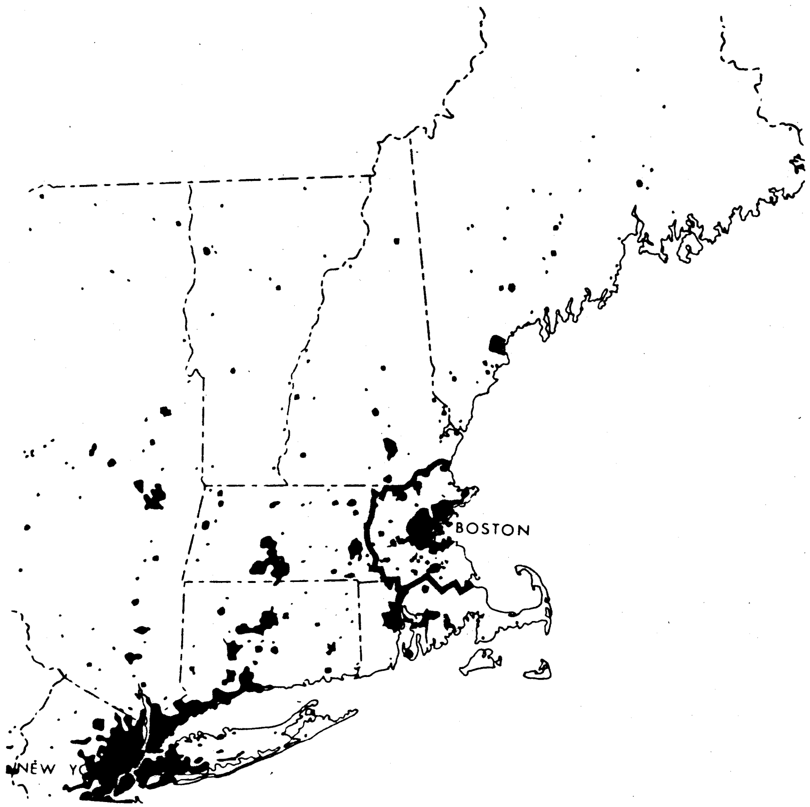
5.1 The Region and its Spatial Structure

The Boston metropolitan region, depicted in Figure 5.1-1, is comprised of 152 cities and towns in eastern Massachusetts and contains the largest concentration of population and economic activity in New England. As shown in the figure, the Standard Metropolitan Statistical Areas (SMSAs) of Brockton, Lowell, Lawrence-Haverhill and Boston are located within the region's boundaries. Of these, the Boston SMSA was the place of residence for more than three-quarters of the region's population of 3.35 million, making it the seventh largest SMSA in the United States, as measured in the 1960 U.S. Census of Population.

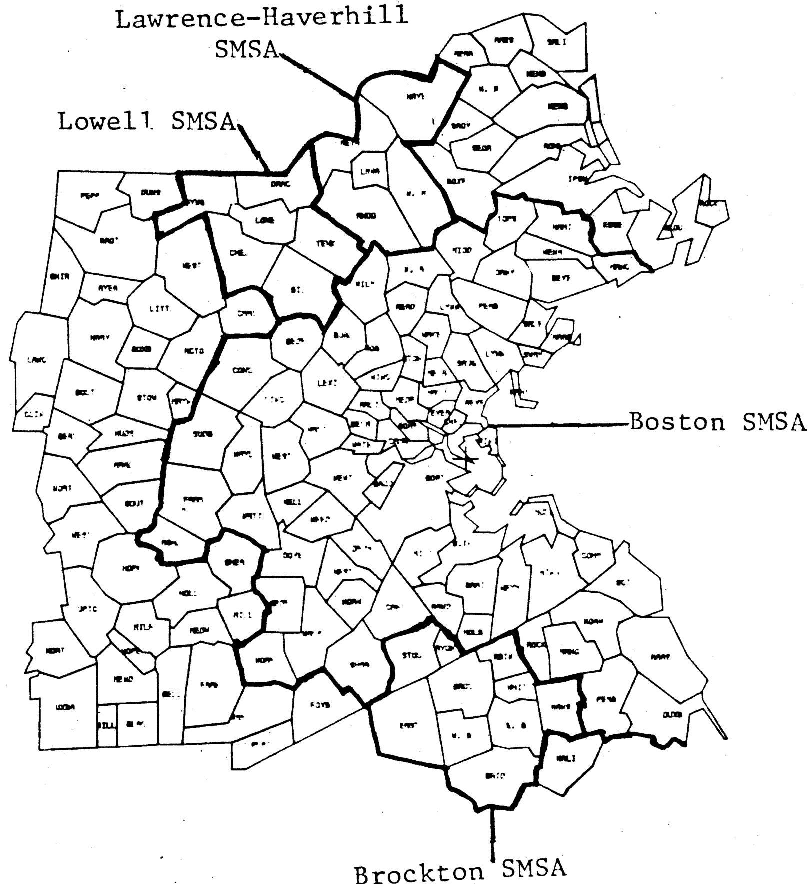
Population and Land Use

The spatial distribution of population by town within the region is shown graphically in Figure 5.1-2 and given in tabular form by SMSA in Table 5.1-1. As is evident from the map, the spatial distribution of population in the region is highly uneven. There are very high densities in excess of 20,000 persons per square mile in the core central cities surrounding and including Boston. In 1963, population densities in the outer ring of core towns, were between 5,000 and 10,000 persons per square mile in and declined rapidly with distance from the center to between 1,500 and

Figure 5.1-1 The Boston Metropolitan Region



The Region's Location in relation to Northeastern Urban Areas



Standard Metropolitan Statistical Areas Contained within the Region

Source: Levin <u>et</u> <u>al</u>.(1963,p.10)

Figure 5.1-2 The Spatial Distribution of Population

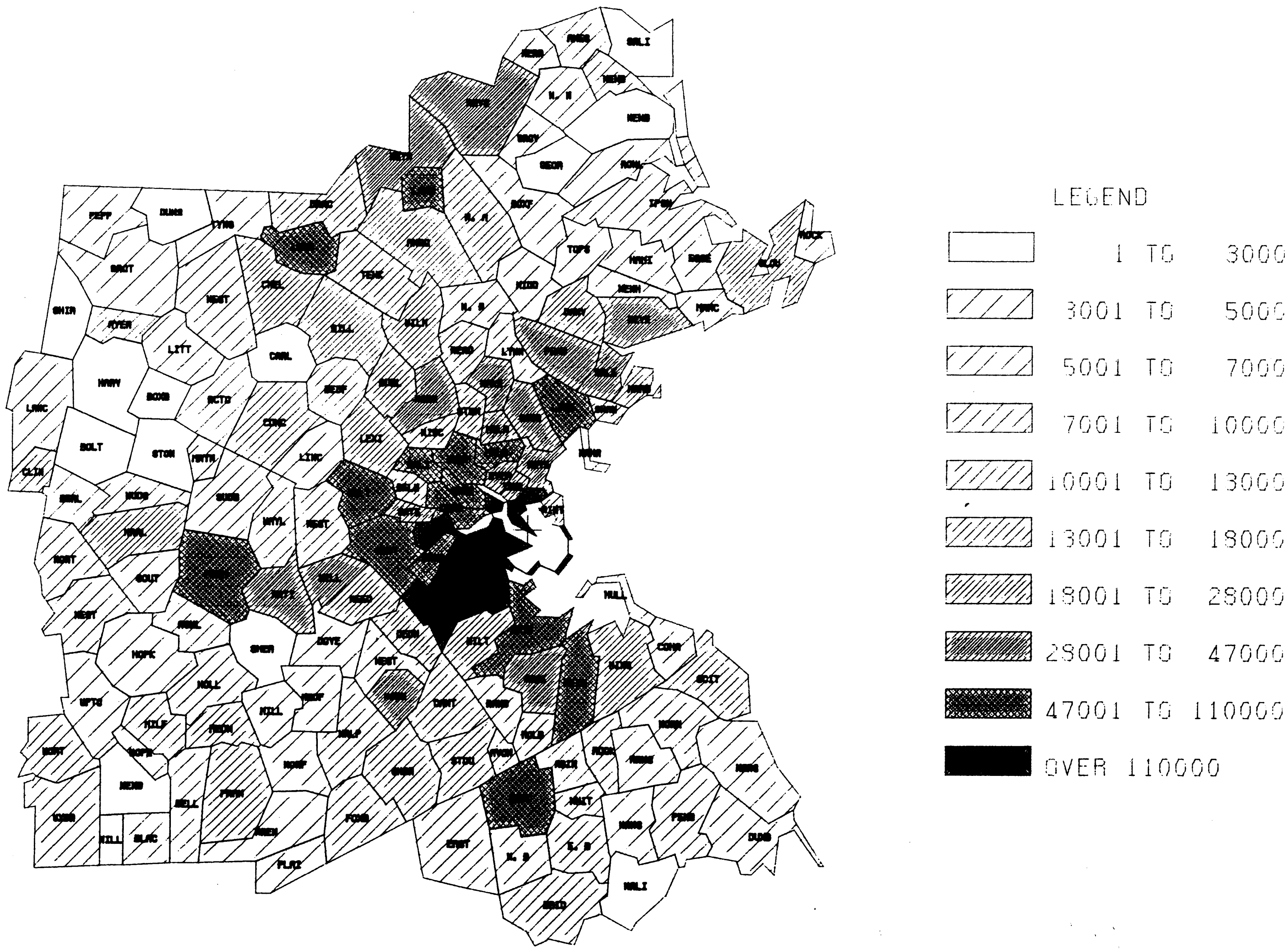


Table 5.1-1

Population of the Region's Standard Metropolitan Statistical Areas

Boston SMSA	2,590,000	77.4%
Brockton SMSA	149,000	4.5%
Lawrence-Haverhill SMSA	175,000	5.2%
Lowell SMSA	158,000	4.7%
Other	274,000	8.2%
TOTAL BOSTON METROPOLITAN REGION	3,346,000	100.0%

Source: U.S. Census of Population, 1960 reported in Levin, *et al.* (1963, p.9)

2,500 persons per square mile in suburban towns. In the outlying towns, which occupy the majority of the region's land area, population densitites were less than 1,000 persons per square mile. With the exception of the central areas of the older, satellite cities[2] in the other SMSA's within the region, all of the towns with more than 4000 persons per square mile were in or near the core of the Boston SMSA (Levin, et al., 1963). However, as may be seen in Figure 5.1-2, population concentrations were somewhat higher along the radial spokes formed by the major highways.

The pattern of land use within the region has been shaped by a wide variety of factors. Among the principal physical determinants of land use has been the location of the city of Boston on a peninsula whose boundaries are formed by the sea and deep tidal estuaries. This site characteristic of the region's core conferred early advantages in the form of easy access to many locations by water transport, but considerably restricted access over land between the core and the region's hinterland. Undoubtedly, the resulting isolation contributed to some degree to the intensity and self-sufficiency of development in the core. Although there has been extensive landfill and

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[2]These other central city areas have declined in population and employment over time and have been surrounded by the expanding metropolis.

roadbuilding, these barriers to land access were not overcome, and traffic delays on the tunnel and bridge connections to other areas are commonplace today. Consequently, despite its centrality, the city of Boston itself is not necessarily the most attractive site from which to maintain regionwide urban delivery services; locations in nearby towns across the estuaries may actually be more accessible to much of the region.

Early settlement patterns have also left their mark on the pattern of land use within the region. Within the core, their principal legacy has been the narrow, irregular, and twisted street pattern which is ill-suited to the accommodation of cars and trucks (Conzen and Lewis, 1976). Outside the core, the very numerous and widely dispersed colonial settlements developed into a satellite pattern of more than 150 distinct political jurisdictions whose centers are separated by copious quantities of open land. The "open" character of land use within the region is reflected in the distribution of land uses, shown in Table 5.1-2, by the high percentage of vacant land.

Apart from vacant land, residential purposes occupy the largest percentage of developed land; approximately 60% is devoted to residential use. In contrast, industrial and

Table 5.1-2

Land Use in the Boston Region, 1963

(in Acres)

Residential	214,933
Commercial	16,506
Social Serv./Recreation	113,873
Manufacturing	23,706
Extrative	9,790
Parking	6,949
Streets and Alleys	78,666
Transportation	10,836
Vacant Buildings	1,271
Vacant Land	872,631
Water and Sewage	179,624
TOTAL	1,528,885

Source: Eastern Massachusetts Regional Planning Project, Comprehensive Land Use Inventory Report, 1963, reported in Boston Redevelopment Authority (1968, p.41) commercial purposes utilized only 4.1% and 3.4% of developed land in 1960, respectively.

In the Boston Regional Survey, Levin et al. (1963, p.32) observed that despite decentralization, core dominance was a significant feature of the intraregional pattern of land use. "The core, which contains only about 6% of the region's total land area, contains one-third of its industrial and commercial land and two-thirds of its multi-family acreage."

The most decentralized land use in the region is the single-family residence. However, whereas most of the available land has been settled within Boston's ring road, Route 128, some 12 miles from region center, beyond this distance, residential development parallels the major radial highways and is separated by large amounts of open land (Levin, et al., op. cit.).

Employment Structure

In 1963, approximately 1,305,000 people were employed within the region. Table 5.1-3 indicates the level and sectoral composition of employment. The distribution of employment among these sectors is reasonably typical of that found in other major metropolitan areas at that time, with a

Table 5.1-3 The Sectoral Composition of Employment in the Region

	#	%
Agriculture	6,832	.52
Mining	660	.05
Construction	64,615	4.95
Manufacturing	428,038	32.80
Transport Comm, & Utilities	75,549	5.7
Wholesale Trade	79,987	6.13
Retail Trade	213,552	16.36
Services	325,253	24.92
Government	110,470	8.47
TOTAL	1,304,956	100.00

larger percentages of manufacturing employment than at present.

The composition of the region's manufacturing sector, which had previously been characterized by the dominance of the production of soft goods such as leather products and textiles, has been rapidly influenced by the pace of technology since the Second World War. During the period from 1947 to 1959, employment in the electrical machinery industry, for example, rose from approximately 10% of the region's employment to approximately 18% to become the region's leading industry. In contrast, the textile industry dropped from 14.9% to 5.2% of total employment during the same period. In 1963, a study conducted for the Commonwealth of Massachusetts found that "regional employment in electrical machinery, ordinance (closely linked to electrical machinery in the region), and instrument manfacturing industries represent over one sixth of national employment in these categories." (Levin, et al., 1963, p. 59).

The impetus for growth in these and other high technology research and development activities can be traced to the considerable intellectual resources concentrated at the region's educational institutions, especially Harvard University and the Massachusetts Institute of Technology.

Conzen and Lewis (1976, p. 15) have noted that the liason between pure research and industrial activity has been sustained for two important reasons.

> "First, industry based on high fabricating skill and low raw material quantities stood a good chance of survival in the light of New England's geographically peripheral position, removed as it is from most raw materials. Such labor-intensive concerns could simply absorb much of the labor pool being released by the existing textile and leather companies.
>
> Second, the pace of scientific research has built into electrical engineering a high degree of technological obsolescence, thus ensuring that the national market would constantly absorb sustained production of ever-new items."

The spatial distribution of manufacturing employment is indicated in the map contained in Figure 5.1-3. High concentrations of manufacturing employment are evident in the core of the region and in the older industrial areas in the Lawrence and Lowell SMSAs. However, by 1960, substantial decentralization and suburbanization of manufacturing establishments had already taken place. While the core areas lost manufacturing employment during the 1947-1960 period, most of the growth in manufacturing took place elsewhere in the region, focusing in towns surrounding the high-speed, high capacity highways in the region - the Massachusetts Turnpike and Route 128. By 1963, the Route 128 area had become nationally known for its high concentration of firms in the electronics industry.

Figure 5.1-3 The Spatial Distribution of Manufacturing Employment

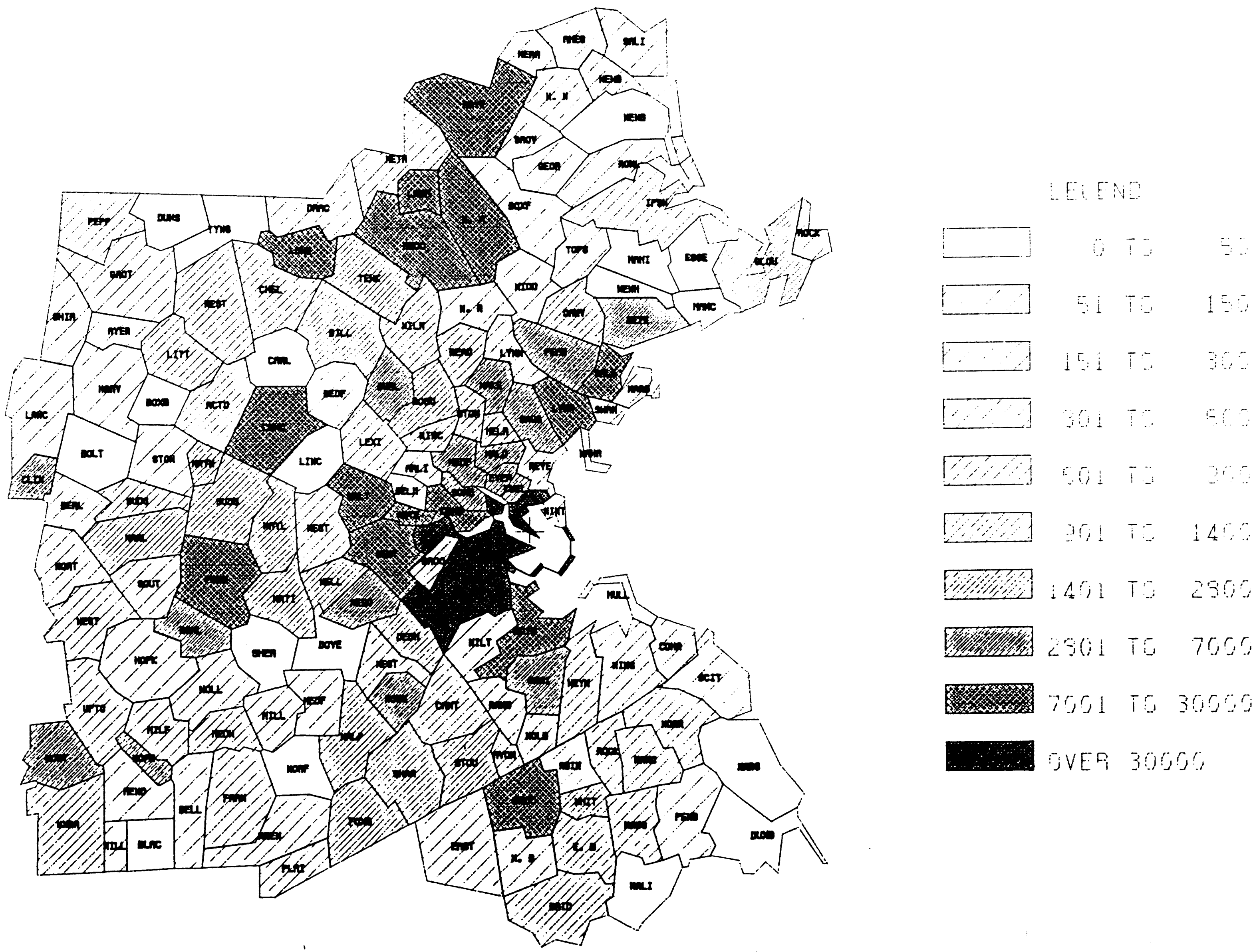
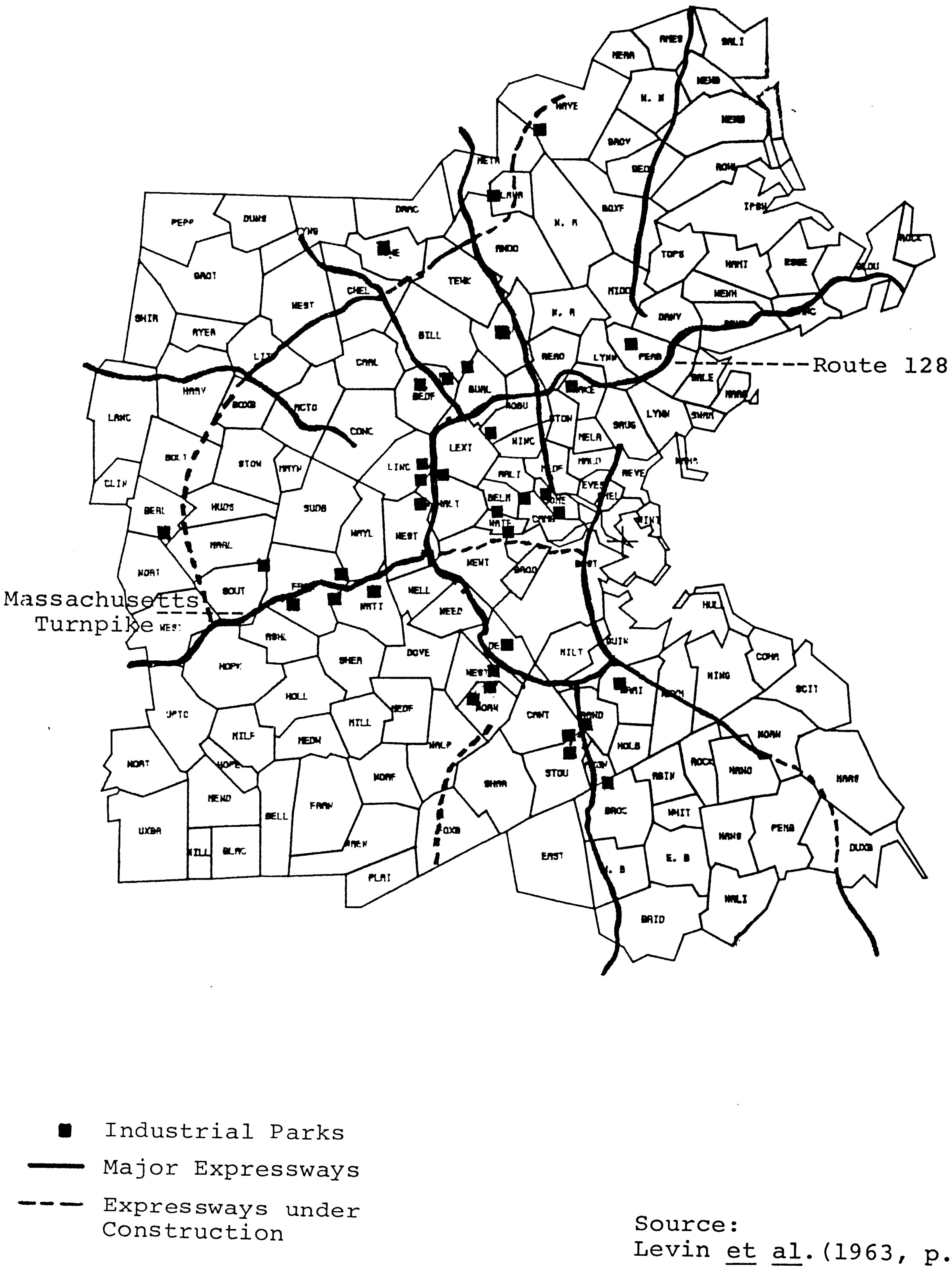


Figure 5.1-4 shows the placement of these highways and the location of the industrial parks in operation in 1961 in the study area. It is especially noteworthy for a study of goods vehicle traffic that nearly two-thirds of the employment in manufacturing in towns on Route 128 was to be found in establishments located on or very close to the highway (Levin, et al., 1963, p.61).

The Boston metropolitan area is the retailing center for New England; there were more than four billion dollars in retail sales in 1958. Although retail sales increased about 3-5% yearly during the 1950's, there was considerable disparity in the distribution of this increase among the region's subareas. The trend of suburbanization is evidenced by the fact while alsolute sales in the Boston CBD declined from 1948 to 1958, "the fast-growing suburban territory on or near Route 128 more than doubled in retail sales volume". (Levin, op. cit., p. 64).

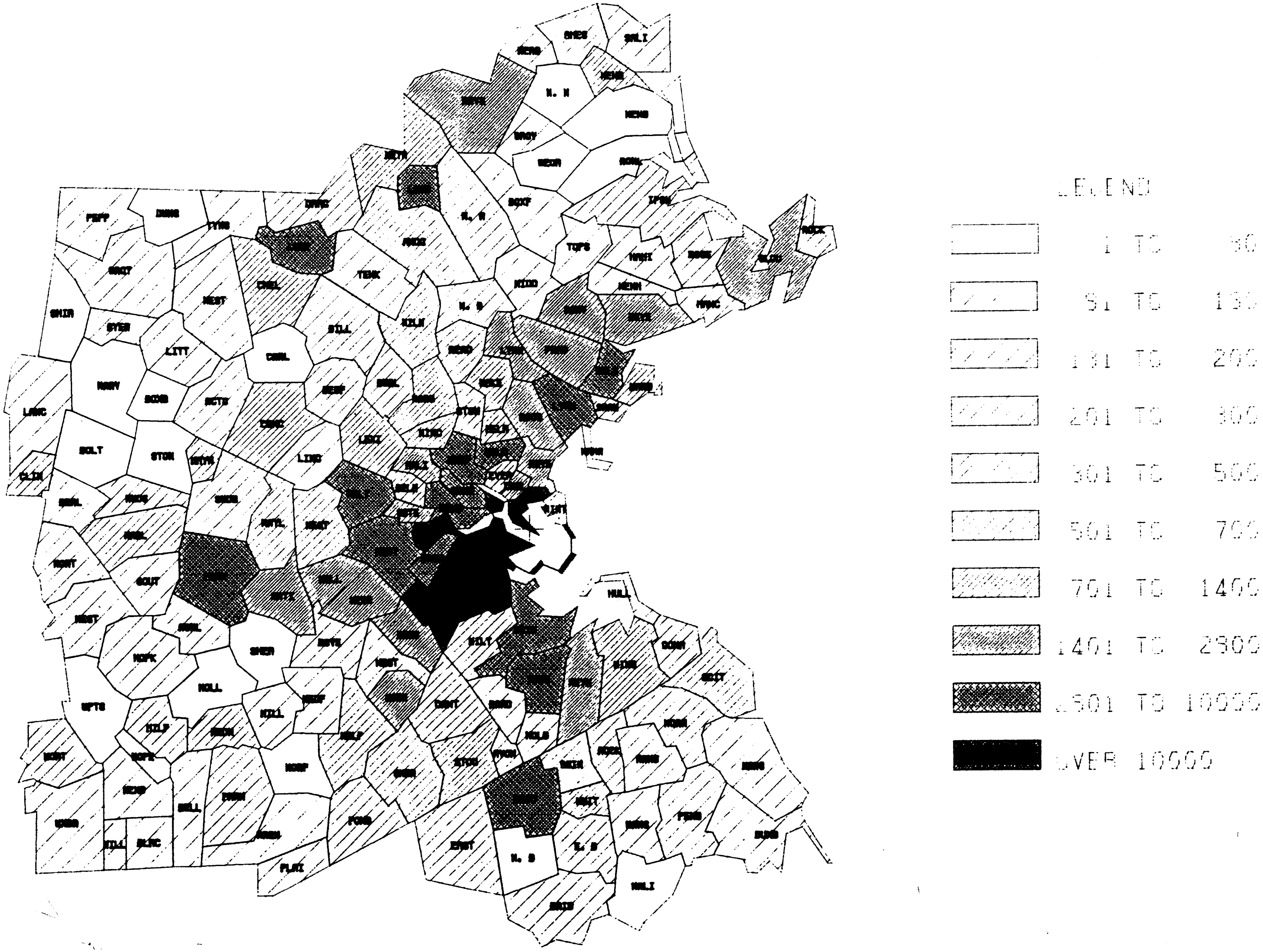
Concomitantly, there was a marked increase in the number of planned shopping centers in newly populated and growing suburbs. The spatial distribution of retail employment, shown in Figure 5.1-5, bears a close correspondence to the spatial distribution of population.

Figure 5.1-4 Expressways and Industrial Parks in Operation, 1961



Source:
Levin _et_ _al_.(1963, p.60)

Figure 5.1-5 The Spatial Distribution of Retail Employment

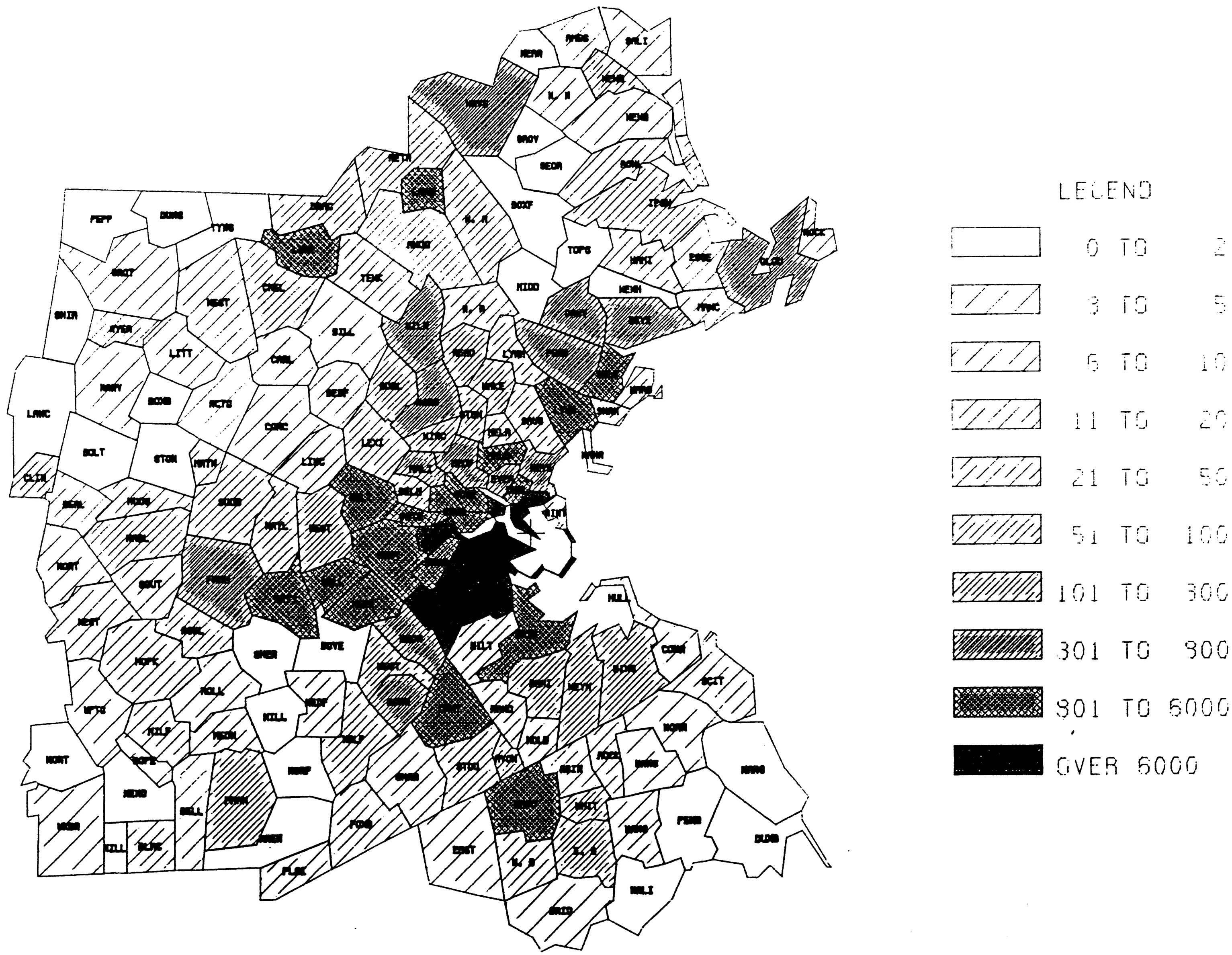


The spatial distribution of wholesaling employment shown in Figure 5.1-6 is somewhat less dispersed than the pattern of retail employment. Employment levels in wholesaling, which accounts for only about 6% of regional employment, belie the magnitude of wholesaling activities within the region. Specifically, wholesale sales exceeded retail sales, suggesting the possibility of fairly high rates of goods vehicle trip generation both in absolute terms and per employee.

Wholesaling was somewhat of a growth sector in the region with increases of about 9% in employment and 20% in sales from 1947 to 1958. Most of this growth in sales and 96% of all wholesale sales in the region were concentrated in the Boston SMSA. However, here too, suburbanization was evident. The following passage from the Boston Regional Survey by Levin, *et al.*, (1963, p. 70-72) indicates the nature of the trend.

> "In recent years, manufacturers, particularly in large corporations, have increased the practice of establishing a system of regional and local warehouses to distribute their products as opposed to construction of numerous manufacturing branch plants. This method of distribution permits closer control over centralized manufacturing operations and offers considerable flexibility in serving local and regional markets. Many of the new warehouses have been built on or near major expressways in suburban locations."

Figure 5.1-6 The Spatial Distribution of Wholesale Employment



Another growth sector in the region's economy was services. This is reflected in Boston's prominance as the commercial, financial, medical, educational, and cultural center for the area. In contrast to the locational trends of many other sectors of the economy, the principal concentration and expansion of service activities has been at the hub of the region. The most evident physical manifestation of this trend has been an office construction boom in downtown Boston.

In 1958, service receipts in the region were estimated by the U.S. Census of Business to be $588 million dollars, of which 90% were in the Boston SMSA and 50% were in the city of Boston. Since service establishments are rather more likely to attract goods vehicle deliveries than to operate their own delivery services, the spatial concentration of services may be one factor leading to locational variation in goods vehicle trip productions and attractions.

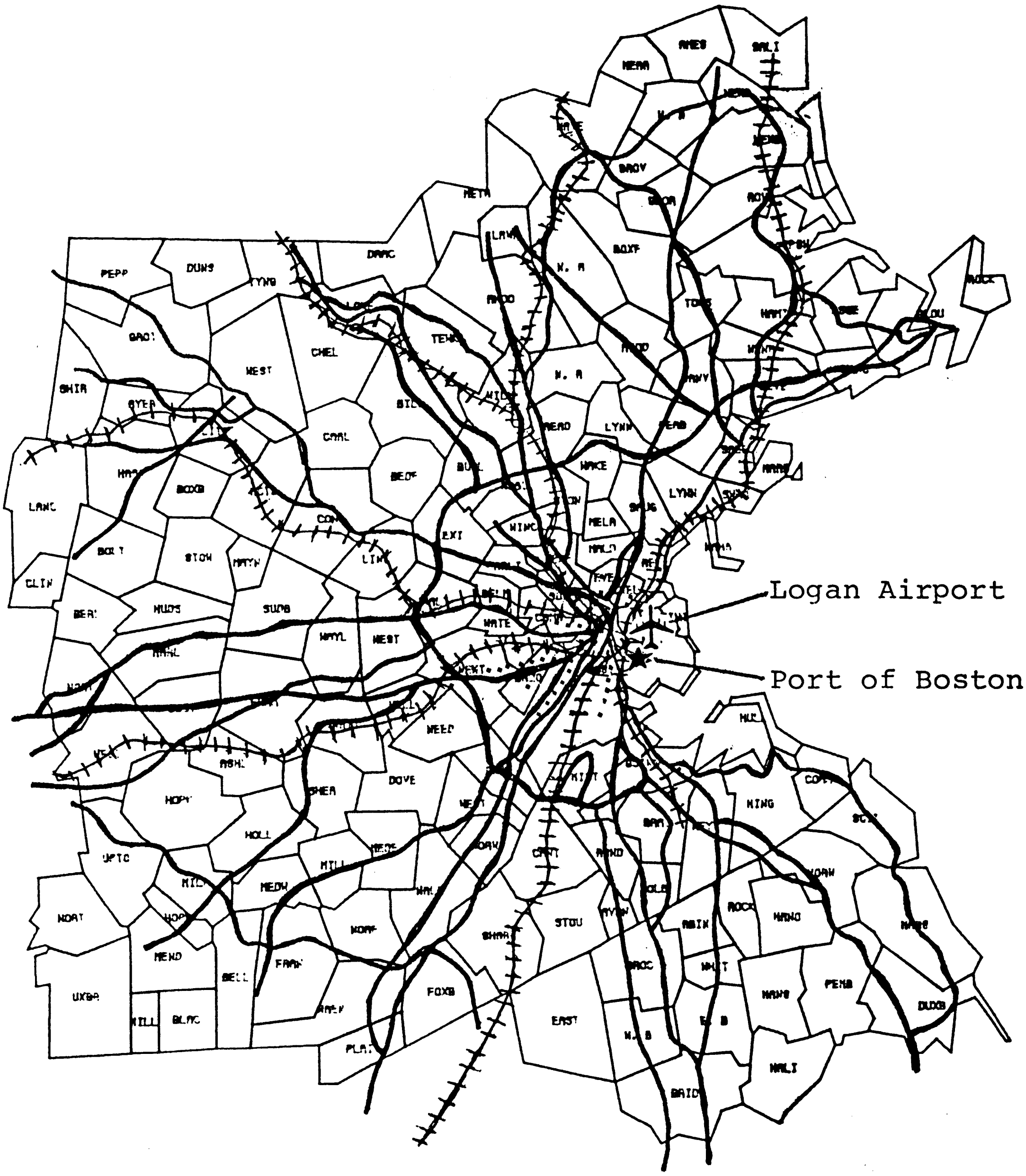
The Transport System

The Boston region has an extensive internal multi-modal transport system which moves large volumes of passengers and freight each day. An highly simplified representation of the modal transport networks and major transport facilities is provided in Figure 5.1-7. One may observe the strong radial orientation of the major highways in 1963. The only major non-radial highway facility was the circumferential Route 128; subsequent to that time, the remainder of an outer belt, Route 495, was also completed.

As in many major U.S. metropolitan areas, the post-war period was marked by large-scale construction and upgrading of the highway network. The highway system in 1963, shown in greater detail in Figure 5.1-8, was one of relative ubiquity although traffic congestion was and remains widespread.

As shown in Figure 5.1-7, the pattern of railroads was also characterized by a strong radial orientation. Although historically sea and rail freight transport were major factors in the growth of Boston as a trading city, by 1963 the role of these modes had declined precipitously. The U.S. Census of Transportation found that 78.7% of the tonnage of manufactured products shipped to other cities from an area slightly larger than the region went by truck, 11.7% by rail, and 7.8% by water. No data are publicly available concerning the amount of local traffic carried by rail in the region, but it is thought that the percentage is small in comparison to trucking and has declined considerably through time (Levin, et al., 1963).

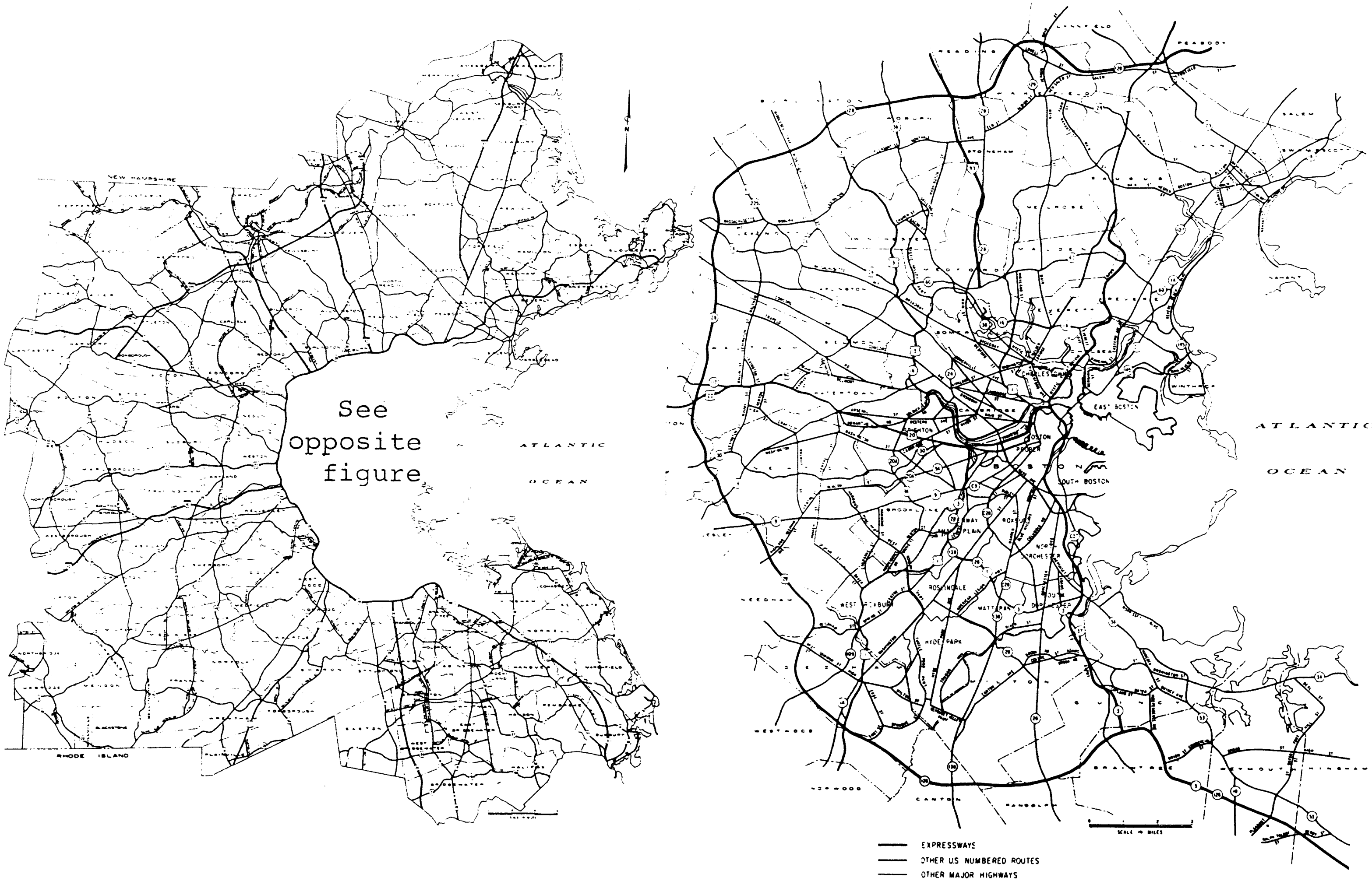
Figure 5.1-7 The Transport System



Highways
Railroads
Rapid Transit

Source:
Levin <u>et</u> <u>al</u>. (1963, pp. 97, 142, 163)

Figure 5.1-8 The Highway System



Source: Wilbur Smith and Associates,(1965,pp. 14-15)

The importance of the port of Boston has also declined for many reasons including Boston's inaccessibility to the rest of the nation. Consequently, the main traffic moving through the port is imports of large amounts of petroleum and small quantities of raw materials destined for local industry. Exports through the port were less significant, amounting to only about one-fifth of the tonnage of imports (Boston Redevelopment Authority, 1968). The region's principal airport, Logan International, is also a conduit for cargo shipments, but the volume in 1963 was small relative to other modes as was noted previously.

With the advent of the motor age, trucks rapidly replaced the horse and wagon as the primary mode of transport within the region. Subsequently, the Boston region fully participated in the national trend of substitution of motor transport for rail for both local and intercity short haul transport. Although hard data on its share were lacking, by 1963 it was widely observed that trucking had become the dominant means of freight transport within the region (Levin, _et al_., 1963). At that time, goods vehicles comprised between ten and twenty percent of the traffic stream. However, in highly industrialized areas goods vehicles accounted for between twenty and forty percent of the traffic on the road network (Levin, _et al_., _op. cit_., p. 101).

Most trucking facilities were located in the denser core areas adjacent to the city of Boston and along major highways. Despite recognition that a plan for truck terminals was needed, it is most important to note that there were "no planned or coordinated major concentrations of terminals in the region" (Levin, et al., op. cit., p. 101).

Since trucks are not the principal users of the road network, to achieve an appreciation of factors influencing trucking operations, it is necessary to take account of other road users. Person travel resulted in approximately 7 million person trips made within the region on an average day in 1963. Of these, more than 6 million person trips were made by car or other modes (including trucks) which make use of the highway network; the remainder of the trips were made by public transit, primarily by subway and bus, with only a small percentage by commuter rail (Boston Redevelopment Authority, 1968).

The spatial pattern of vehicular traffic exhibited a strong radial orientation to the center of the region in Boston proper. There was considerable locational variation in traffic densities which increased dramatically with decreasing distance from region center. In Boston proper, there were more than 400,000 daily per trip ends per square mile in 1963-64. Other core locations within the City of Boston and the inner towns attracted approximately 50,000 person trip ends per day. In contrast, the majority of the towns within the region had traffic densities which averaged less than 5,000 person trip ends per square mile (Wilbur Smith and Associates, 1965).

The overall pattern of traffic intensity was similar to the distribution of employment and population, with the heaviest concentration of trips within the Route 128 perimeter. This suggests that there was a close correspondence and some measure of conflict between patterns of car and goods vehicle traffic.

5.2 The Data Base for the Empirical Analysis

The data for this study have been drawn from surveys conducted under the aegis of the continuing, comprehensive, and cooperative planning process for the region as managed by the Eastern Massachusetts Regional Planning Project. During the last decade, studies of land use, population, employment, transportation, and economic growth have been initiated by this agency, its successors, and supporting institutions. The primary data files utilized in this research were obtained on computer tape from the Massachusetts Department of Public Works and consisted of a socio-economic data file, trip records from survey of goods vehicle movements, and a matrix of off-peak interzonal travel times. Each of these files was coded for the 626 traffic zones, shown by town in Figure 5.2-1, which cover the region.

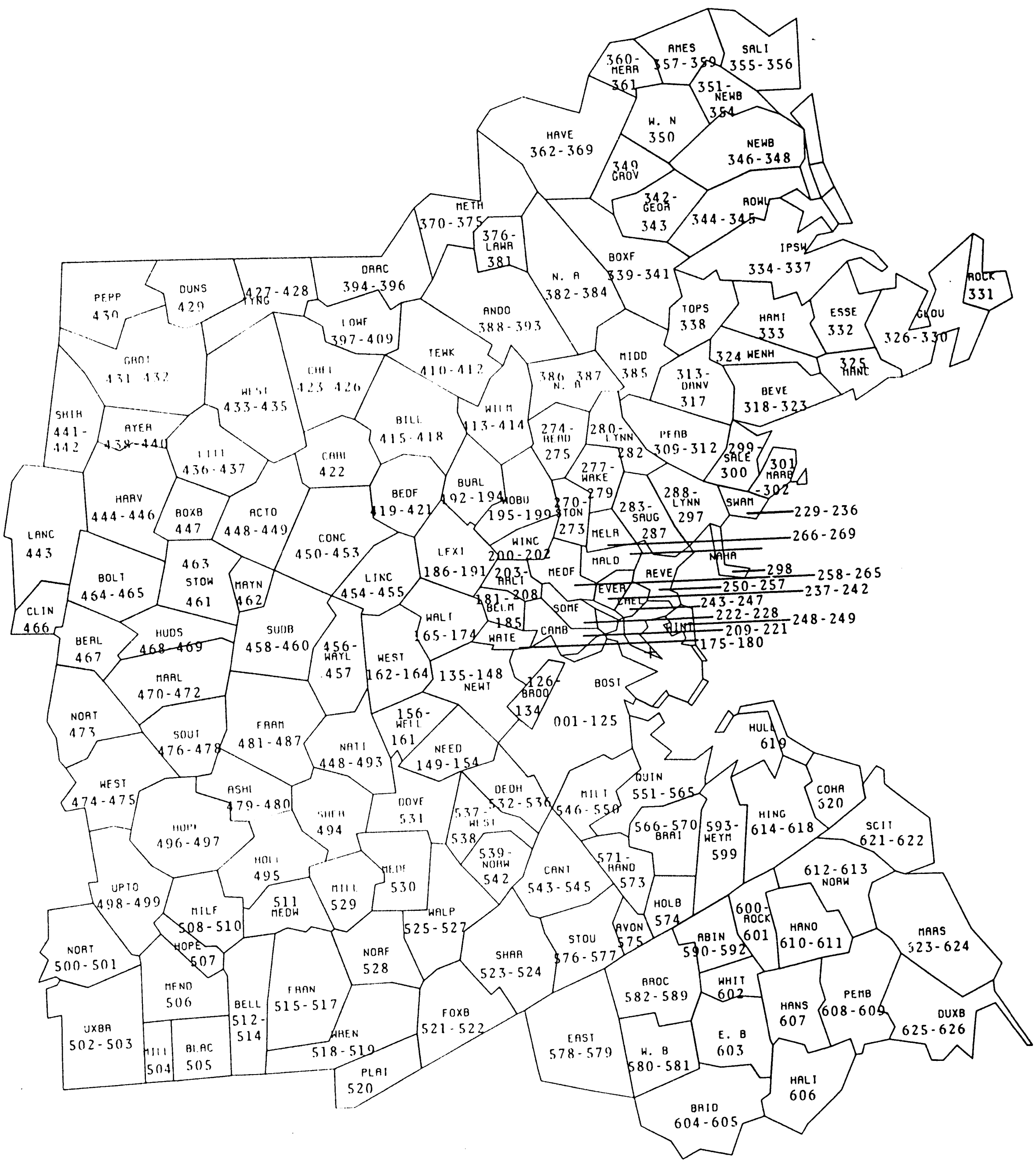
The Socio-economic Data

The socio-economic data available for this study consisted of descriptions of the characteristics of the level and mix of industrial, commercial, institutional, and residential activity in each traffic zone. These data were compiled by the Eastern Massachusetts Regional Planning Project primarily from Federal and State Census reports, the employment records of the Massachusetts Division of Employment Security, and land use and transport inventories,[3]

Apart from zonal measures of population and area, the activity system data used in the empirical study were employment measures. The employment data was assembled from a complete census of business establishments conducted by the Commonwealth of Massachusetts (Vogt-Ivers and

[3]The documentation for the socio-economic data includes Vogt-Ivers and Associates (1969), Wilbur Smith and Associates (1965), and Tittemore and Jacobs (1969).

Figure 5.2-1 The 626 Traffic Zones



Associates, 1969). As a result, the data was the most accurate and comprehensive source of activity system data (Boston Redevelopment Authority, 1968). In the compilation of the socio-economic data, zonal employment levels were tabulated for a classification distinguishing 100 different industrial, commercial, and institutional activities.

<u>The Goods Vehicle Survey</u>

A comprehensive transport and traffic inventory was conducted by the firm of Wilbur Smith and Associates (WSA) for the Boston Regional Planning Project (WSA, 1965). Origin-destination studies were conducted for internal passenger travel, transit, taxis, and goods vehicles.

The goods vehicle survey data were obtained by means of interviews performed during the winter of 1963-64 with the operators of a random sample of 10% of all the goods vehicles registered within the study area. A response rate of 77.5% was achieved. Many of the vehicles for which travel data could not be secured had been sold or were out of service because they had been scrapped or were being repaired. However, the precise number of vehicles in each of these non-response sub-categories was not recorded.

Vehicles engaged in the carriage of mail and express were not included in the sample. However, a separate survey with the same questionnaire was made of a random 10% sample of vehicles operated within the region by governmental institutions.

The instrument employed for both surveys is shown in Figure 5.2-2. As is indicated, a complete log of the prior day's trips was solicited. For each trip, information was collected on its timing and sequence within the daily pattern, its origin and destination location and land uses, the commodity picked up or delivered and the number of deliveries made. Information was also collected on trip purpose, although the list of trip purposes for business use did not include very detailed or comprehensive information.

Information collected for each vehicle included the industry and business classification of the operator, the type of vehicle, and a few summary measures for the prior day's travel pattern. These measures were the estimated day's mileage within the survey area, the total number of trips, and the total number of deliveries made on all the trips.

Descriptive statistics from the survey data profiling goods vehicle traffic within the region will be presented in

Figure 5.2-2 The Goods Vehicle Survey Form

1963-1964
COMPREHENSIVE TRAFFIC AND TRANSPORTATION INVENTORY
COMMONWEALTH OF MASSACHUSETTS
BOSTON REGIONAL PLANNING PROJECT
TRUCK REPORT

ADMINISTRATIVE RECORD

18 INTERVIEWER'S RECORD

PERSON INTERVIEWED

TITLE

IF INTERVIEWED ✓

VEHICLE DRIVER 1. 2. 3.

CALLS
1. TIME ____ DATE ____
2. TIME ____ DATE ____
3. TIME ____ DATE ____
4. TIME ____ DATE ____

NOTES

LETTER RECEIVED ☐ YES ☐ NO ☐ DON'T REMEMBER

INCOMPLETE INTERVIEW REASON

INC CODE

I CERTIFY THAT ALL INFORMATION ON THIS FORM IS CORRECT AND TRUE.

INTERVIEWER'S SIGNATURE

19 SUPERVISOR'S COMMENTS

PHONE VERIFIED — NAME ____ DATE ____
FIELD VERIFIED — NAME ____ DATE ____
FINAL APPROVAL NAME ____ DATE ____
EXTRA CODE 1 2 3 4

82-963

1. OWNER ____
PAGE ____ OF ____
CARD NO: 0 4
2. ADDRESS ____
TRAVEL MONTH & DAY
CITY OF TOWN ____
SAMPLE NO.
3. TELEPHONE NO. ____ STATE LICENSE NO. ____ MAKE OF TRUCK ____ YEAR OF MFG. ____

4. TYPE TRUCK 1. NON-CONTRACT CARRIER 2. CONTRACT CARRIER

SINGLE UNIT TRUCK
2 2 AXLE FOUR TIRES
3 2 AXLE SIX TIRES
4 3 AXLE SINGLE UNIT
5 4 AXLE COMBINATION

SEMI TRAILER
6 3 AXLE
7 4 AXLE
8 5 AXLE
9 5 AXLE COMBINATION

COMPANY VEHICLE NO ____

5. DAY AND DATE OF TRAVEL? YESTERDAY) ____ DAY ____ DATE ____ REG. GROSS WGT. (CWT) ____
6. INDUSTRY ____ BUSINESS ____
7 ESTIMATED DAYS MILEAGE WITHIN SURVEY AREA ____
8. TOTAL NUMBER OF DELIVERIES ____ TOTAL NUMBER OF TRIPS ____

9 DRIVER NUMBER	10 TRIP NUMBER	11 WHERE DID THIS TRIP BEGIN? ADDRESS AND LAND USE — ORIGIN —	12 WHERE DID THIS TRIP END? ADDRESS AND LAND USE — DESTINATION —	TRIP PURPOSE: 13 BUSINESS USE (FROM / TO)	TRIP PURPOSE: 14 PERSONAL USE (FROM / TO)	15 MID-POINT TIME	16 COMMODITY	17 NO. OF DELIVERIES
		ADDRESS; SECT. & TOWN (1 RET 2 WHSL 3 MFG); LAND USE	ADDRESS; SECT. & TOWN (1 RET 2 WHSL 3 MFG); LAND USE	1 HOME BASE 1; 2 PERS USE 2; 3 RETAIL DEL 3; 4 WHSL DEL 4; 5 TRASH COLL 5; 6 MAIL & EXP 6; 7 CONSTR 7; 8 MAINT & REP 8; 9 FURN TRANS 9; 0 OTHER (EXPL.) 0	1 WORK 1; 2 PERS BUS 2; 3 RECREATION 3; 4 SCHOOL 4; 5 SOCIAL 5; 6 CH TR MODE 6; 7 SHOP CONV 7; 8 SHOP GOODS 8; 9 SERVE PASS 9; 0 HOME 0	A.M. P.M.		
		ADDRESS; SECT. & TOWN (1 RET 2 WHSL 3 MFG); LAND USE	ADDRESS; SECT. & TOWN (1 RET 2 WHSL 3 MFG); LAND USE	1 HOME BASE 1; 2 PERS USE 2; 3 RETAIL DEL 3; 4 WHSL DEL 4; 5 TRASH COLL 5; 6 MAIL & EXP 6; 7 CONSTR 7; 8 MAINT & REP 8; 9 FURN TRANS 9; 0 OTHER (EXPL.) 0	1 WORK 1; 2 PERS BUS 2; 3 RECREATION 3; 4 SCHOOL 4; 5 SOCIAL 5; 6 CH TR MODE 6; 7 SHOP CONV 7; 8 SHOP GOODS 8; 9 SERVE PASS 9; 0 HOME 0	A.M. P.M.		
		ADDRESS; SECT. & TOWN (1 RET 2 WHSL 3 MFG); LAND USE	ADDRESS; SECT. & TOWN (1 RET 2 WHSL 3 MFG); LAND USE	1 HOME BASE 1; 2 PERS USE 2; 3 RETAIL DEL 3; 4 WHSL DEL 4; 5 TRASH COLL 5; 6 MAIL & EXP 6; 7 CONSTR 7; 8 MAINT & REP 8; 9 FURN TRANS 9; 0 OTHER (EXPL.) 0	1 WORK 1; 2 PERS BUS 2; 3 RECREATION 3; 4 SCHOOL 4; 5 SOCIAL 5; 6 CH TR MODE 6; 7 SHOP CONV 7; 8 SHOP GOODS 8; 9 SERVE PASS 9; 0 HOME 0	A.M. P.M.		
		ADDRESS; SECT. & TOWN (1 RET 2 WHSL 3 MFG); LAND USE	ADDRESS; SECT. & TOWN (1 RET 2 WHSL 3 MFG); LAND USE	1 HOME BASE 1; 2 PERS USE 2; 3 RETAIL DEL 3; 4 WHSL DEL 4; 5 TRASH COLL 5; 6 MAIL & EXP 6; 7 CONSTR 7; 8 MAINT & REP 8; 9 FURN TRANS 9; 0 OTHER (EXPL.) 0	1 WORK 1; 2 PERS BUS 2; 3 RECREATION 3; 4 SCHOOL 4; 5 SOCIAL 5; 6 CH TR MODE 6; 7 SHOP CONV 7; 8 SHOP GOODS 8; 9 SERVE PASS 9; 0 HOME 0	A.M. P.M.		
		ADDRESS; SECT. & TOWN (1 RET 2 WHSL 3 MFG); LAND USE	ADDRESS; SECT. & TOWN (1 RET 2 WHSL 3 MFG); LAND USE	1 HOME BASE 1; 2 PERS USE 2; 3 RETAIL DEL 3; 4 WHSL DEL 4; 5 TRASH COLL 5; 6 MAIL & EXP 6; 7 CONSTR 7; 8 MAINT & REP 8; 9 FURN TRANS 9; 0 OTHER (EXPL.) 0	1 WORK 1; 2 PERS BUS 2; 3 RECREATION 3; 4 SCHOOL 4; 5 SOCIAL 5; 6 CH TR MODE 6; 7 SHOP CONV 7; 8 SHOP GOODS 8; 9 SERVE PASS 9; 0 HOME 0	A.M. P.M.		

the next chapter. More detailed information concerning the data collection and coding procedures is provided in Wilbur Smith and Associates (1963).

Chapter 6 An Empirical Analysis of Goods Vehicle Trip Generation

This chapter presents an empirical analysis of the relationship between goods vehicle trip generation and the spatial structure of the Boston region. The analysis is aggregate in the sense that it is based on activity and transport system data pertaining to traffic zones rather than to individual firms. The empirical analysis is also "disaggregated" in the sense that the urban goods transport demand of different activities is investigated separately and also in that trip generation is studied in terms of its components.

The basic objectives of the empirical analysis were three-fold. One objective was to provide statistical measures of important aspects of urban freight transport, such as vehicle ownership, tour frequencies, and trip chaining, which have generally been ignored in the literature. This is done in section 6.1 which provides a descriptive overview of the data and some of the salient characteristics of urban goods transport demand.

A second objective was that of providing a limited empirical test of the theory set forth in Chapter 3. Although a test of a disaggregate theory based on aggregate data is indirect at best (and possibly misleading), the theory has important implications for the structure and content of an aggregate analysis which could be tested against available empirical data.

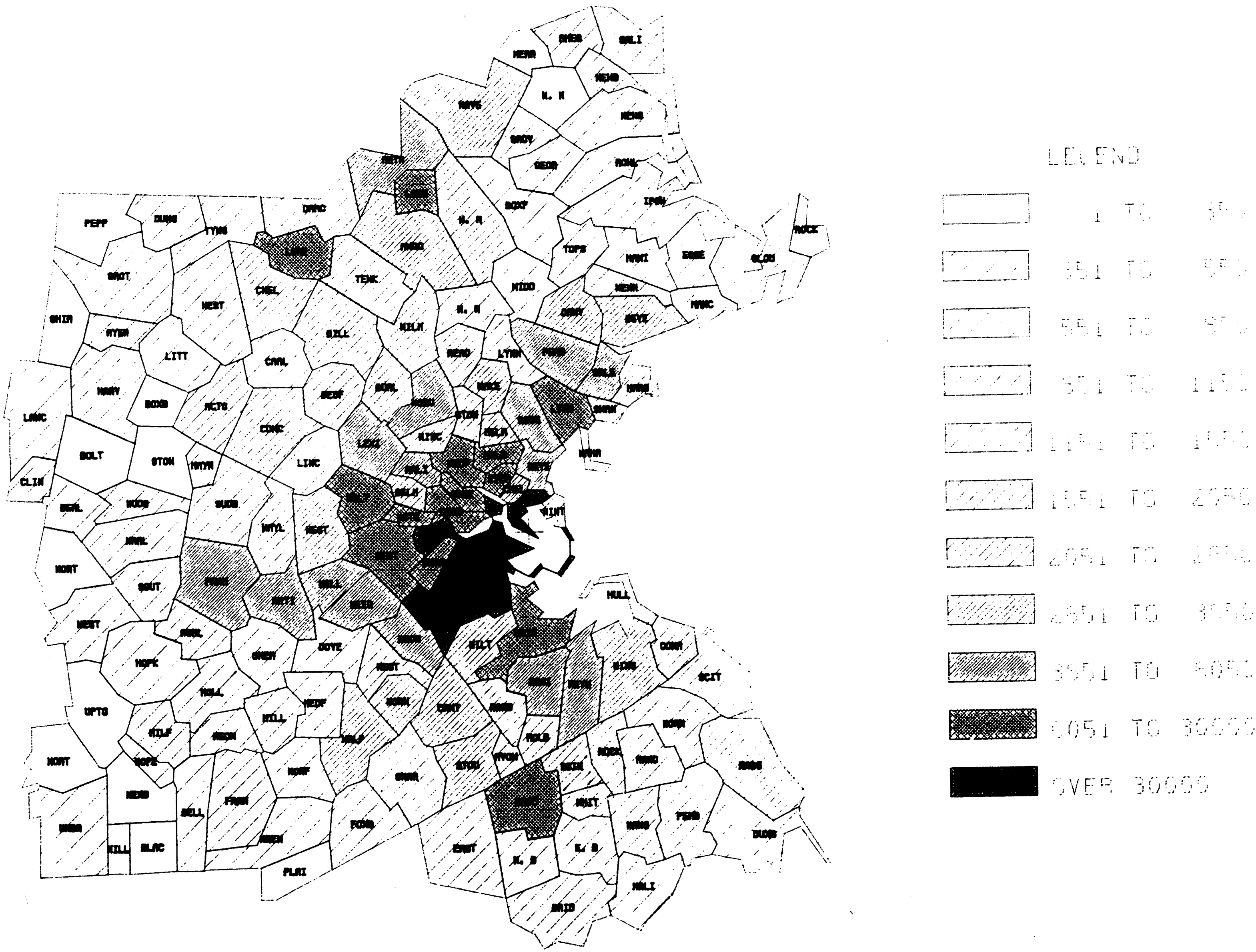
The third objective of the empirical analysis was to quantify the determinants of goods vehicle traffic and test hypotheses concerning its relationship to the activity/transport system. Accomplishing this and the second objective, which is closely related, requires the utilization of multivariate statistical models. Section 6.2 discusses hypothesis concerning the determinants of demand for urban goods vehicle trips in terms of the model structure described in Chapter 4. Specifications are proposed for a system of equations whose endogenous variables are transport provider consignment, trip, and tour frequencies; trip attraction; and total trip generation. The results of the estimation of empirical models of goods vehicle trip generation by manufacturing, for-hire transport, wholesale and retail trade, and total activity are presented in section 6.3. Finally, major conclusions are summarized in section 6.4.

6.1 Descriptive Measures of Goods Vehicle Transport

Goods vehicle movements constituted a sizeable fraction of total vehicle movements in the Boston metropolitan area as measured in the transport inventory conducted during the winter of 1963-1964. On the average, there were more than 878,000 goods vehicle trips each day within the region, accounting for approximately 16% of the total number of trips made by all motor vehicles. In addition, 37,800 interregional goods vehicle trips (10.4% of all traffic crossing the external cordon) either originated or terminated within the area, and another 2,800 "through" trips were also observed. Thus the preponderance of goods vehicle trips were wholly contained within the region.

The pattern of goods vehicle trip ends is displayed in Figure 6.1-1. This pattern bears a strong similarity to the road network, depicted in Figure 5.1-8, at the time of data collection, and to the spatial distribution of population and employment. Approximately 76% of all goods vehicle trips were wholly contained within the Boston SMSA. Of the remaining trips, 69% both originated and terminated within the three other SMSAs of Lowell, Brockton, and Lawrence-Haverhill. Thus, the highest levels of goods transport activity were concentrated in the most densely settled subareas of the region.

Figure 6.1-1 Goods Vehicle Trip Ends



Most major industry groups in metropolitan areas are providers of urban goods transport. The distribution of trips by the sector performing the goods carriage is indicated in Table 6.1-1. Wholesale and retail trade accounted for more than 42% of the trips made by all sectors. Almost 3/4 of all goods vehicle trips were produced by the trade, manufacturing, and for-hire transport sectors. High rates of trip-making per employee were found in agriculture (including forestry and fishery), mining, construction, transport (including communications and utilities), and trade. The trip rates for the first two sectors may not be typical of these activities in other settings as these were very minor, and possibly very specialized, industries within the region.

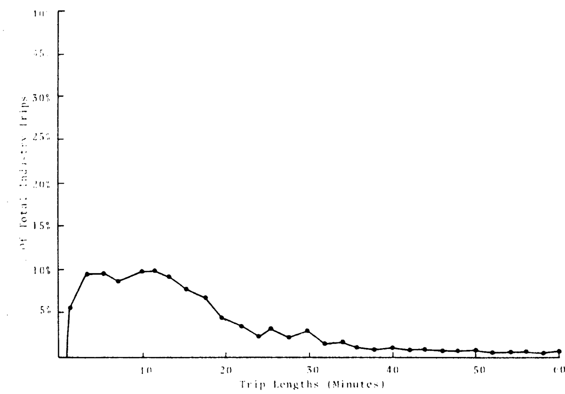
The short length of goods vehicle trips, hypothesized to be a direct consequence of trip chaining, is indicated by the high incidence of intrazonal trips in the survey data. Approximately 40% of all trips originated and terminated within the same traffic zone.

Trip length distributions for selected industries have been plotted in Figure 6.1-2 for two minute intervals of travel time. Only the first 30 intervals are shown as the percentage of trips in succeeding intervals is small, although trips of up to 2 hours in duration were observed in

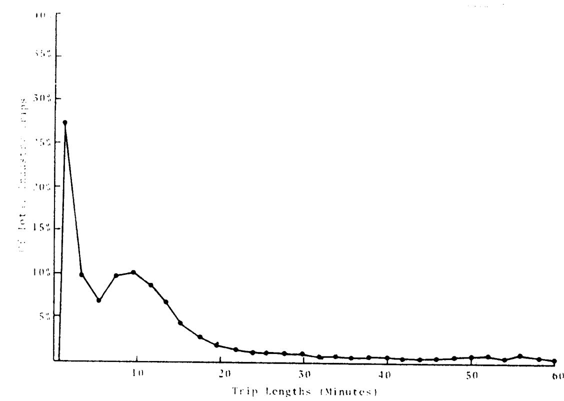
TABLE 6.1-1 Industry Vehicle Trips

Industry	Trips	Percent of Total Trips	Average # Trips/Employee
Agriculture	22360	2.6	3.3
Mining	4306	.5	6.5
Construction	75384	8.7	1.2
Manufacturing	116251	13.4	.3
Transport, etc.	157071	18.1	2.1
Trade	368510	42.5	1.3
Services	75143	8.7	.2
Government	47401	5.5	.4

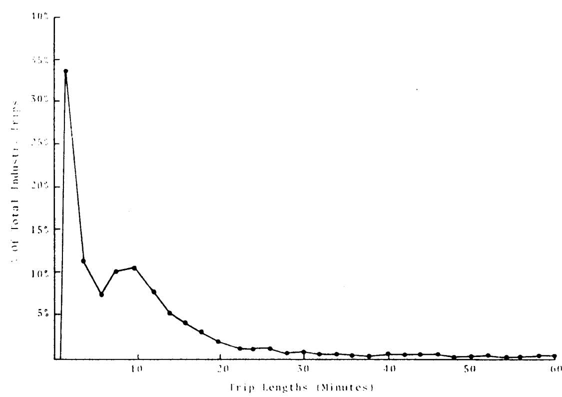
Figure 6.1-2 Industry Trip Length Distributions



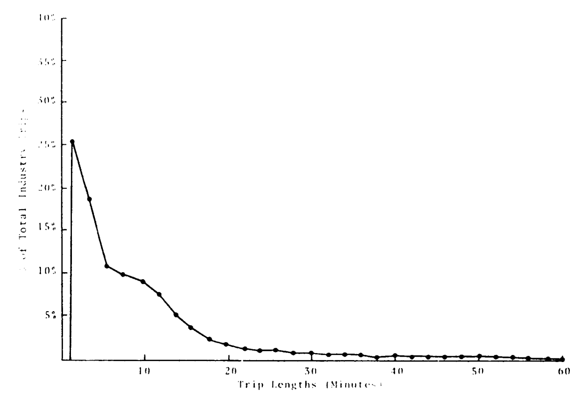
CONSTRUCTION



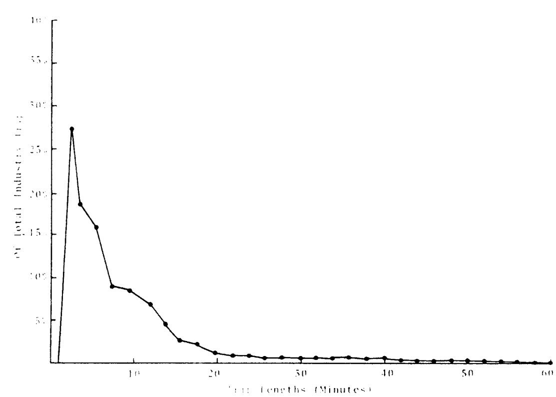
MANUFACTURING



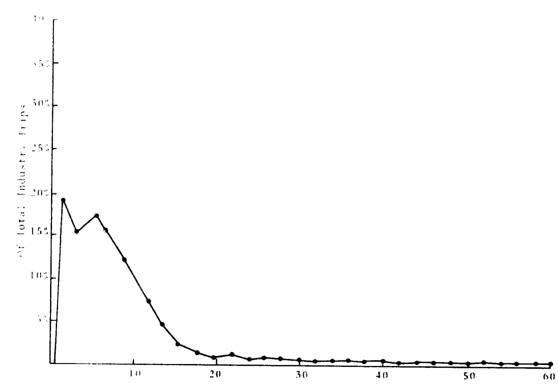
TRANSPORT, COMMUNICATIONS, & UTILITIES



WHOLESALE & RETAIL TRADE



SERVICES



GOVERNMENT

the data. Summary trip length statistics are given in Table 6.1-2.

Noticeable differences in mean industry trip lengths are evident, although the trip length distributions for manufacturing, wholesaling, and retailing are similar. For the for-hire transport industry, mean trip lengths were longer than the average for all sectors, and longer than those indicated in Table 6.1-2 as they were averaged with communications and utilities. Mean trip lengths for the construction industry were also longer than for other industries. The utilization of goods vehicles in the construction industry differs from their utilization in other activities, and it is likely that the longer than average trip lengths for construction are the direct result of a lower degree of trip chaining.

Estimates of the total number of deliveries, the percentage of total deliveries made by each industry, and the average number of industry deliveries per day per employee are shown in Table 6.1-3. As in the case of trip generation rates, considerable variation in delivery frequency rates are in evidence. Further, despite the fact that there are somewhat more deliveries per day than trips for many activities, there is a high correlation between

Table 6.1-2 Industry Trip Length Distributions

Industry	Avg. Length (min.)	Std. Deviation (min.)	Total Hrs. of Travel
Construction	14.35	11.14	18035.74
Manufacturing	8.24	9.86	15972.44
Transport, etc.	9.72	10.70	25444.89
Wholesale/Retail	7.86	8.26	48263.85
Services	6.75	7.09	7112.22
Government	7.68	8.37	6074.2

Table 6.1-3 Industry Delivery Frequencies

Industry	Total Deliveries	Percent of Total	Avg. Number of Deliveries/Employee
Agriculture	34464	3.59	5.04
Mining	2719	.28	4.12
Construction	39092	4.07	.60
Manufacturing	139732	14.55	.33
Transport, Comm. & Utilities	164959	17.18	2.18
Trade	419124	43.66	1.43
Services	112841	11.75	.35
Government	47140	4.91	.43

trips and deliveries generated per employee across the industry groups.

The estimated number and percentage of vehicle tours generated by industry per day and the average number of tours generated per employee are given in Table 6.1-4. As would be expected as a consequence of trip chaining, the industry tour frequencies are considerably lower than the corresponding trip and delivery frequencies.

An estimated 64,970 goods vehicles were owned or operated within the region by the industries indicated in Table 6.1-5. Almost one third of all the trucks operated in the region were utilized by wholesale and retail trade. With the exception of the transport, communications, and utilities sector, the activities operating the greatest number of vehicles did not necessarily have the highest rates of vehicle ownership/control.[1]

An indication of the importance of the private provision of goods transport is provided by the distribution of license types for the vehicles operated in the region. Overall, an estimated 84.8% of all vehicles were licensed by

---

[1]Once again we repeat the caveat that the statistics for agriculture and mining may be atypical of urban goods movement and also atypical for these activities in other locations.

Table 6.1-4 Industry Tour Frequencies

Industry	Number Tours	Percent of Total	Tours/Employee
Agriculture	8673	7.67	1.27
Mining	1383	1.22	2.10
Construction	20948	18.53	.324
Manufacturing	12349	10.92	.029
Transport, Comm., & Utilities	16651	14.73	.220
Trade	36712	32.48	.125
Services	7458	6.60	.023
Government	8867	7.84	.080

Table 6.1-5 Goods Vehicles Operated

Industry	No. Vehicles	Percent	No. Vehicles/Employee
Agricultural	6137	9.44	.898
Mining	481	.74	.729
Construction	14236	21.91	.220
Manufacturing	6699	10.31	.016
Transport, Comm. & Utilities	11709	18.02	.155
Trade	19864	30.57	.068
Services	1741	2.68	.005
Government	4103	6.32	.037

private operators, 8.0% by for-hire transport, and 7.2% had public licenses.
The importance of the private provision of goods transport is further illustrated in Figure 6.1-3 by the percentage of each industry's trips provided with vehicles of different license types.

A variety of general and special purpose goods vehicles are utilized within metropolitan areas, and as was indicated in Chapter 5, many of these were distinguished in the goods vehicle survey. Table 6.1-6 reports the percentages of vehicles by type for the different industry groups.

Most trips are made in the region by 2-axle, 4-tire vehicles and 2-axle, 6-tire vehicles. The distribution of industry trips made by the four major vehicle types is shown in Figure 6.1-4. Some sectoral variation is exhibited, with agriculture, manufacturing, construction, trade, and services differing noticeably from mining and government.

Differential rates of trip-making by vehicle type are evident from the comparison of the corresponding entries in Table 6.1-6 and Figure 6.1-4. For example, small (2-axle, 4-tire) vehicles operated by manufacturing, transport, communications, and utilities, trade, and services account for disproportionate shares of tripmaking.

Figure 6.1-3 Industry Trips by Percentage License Type

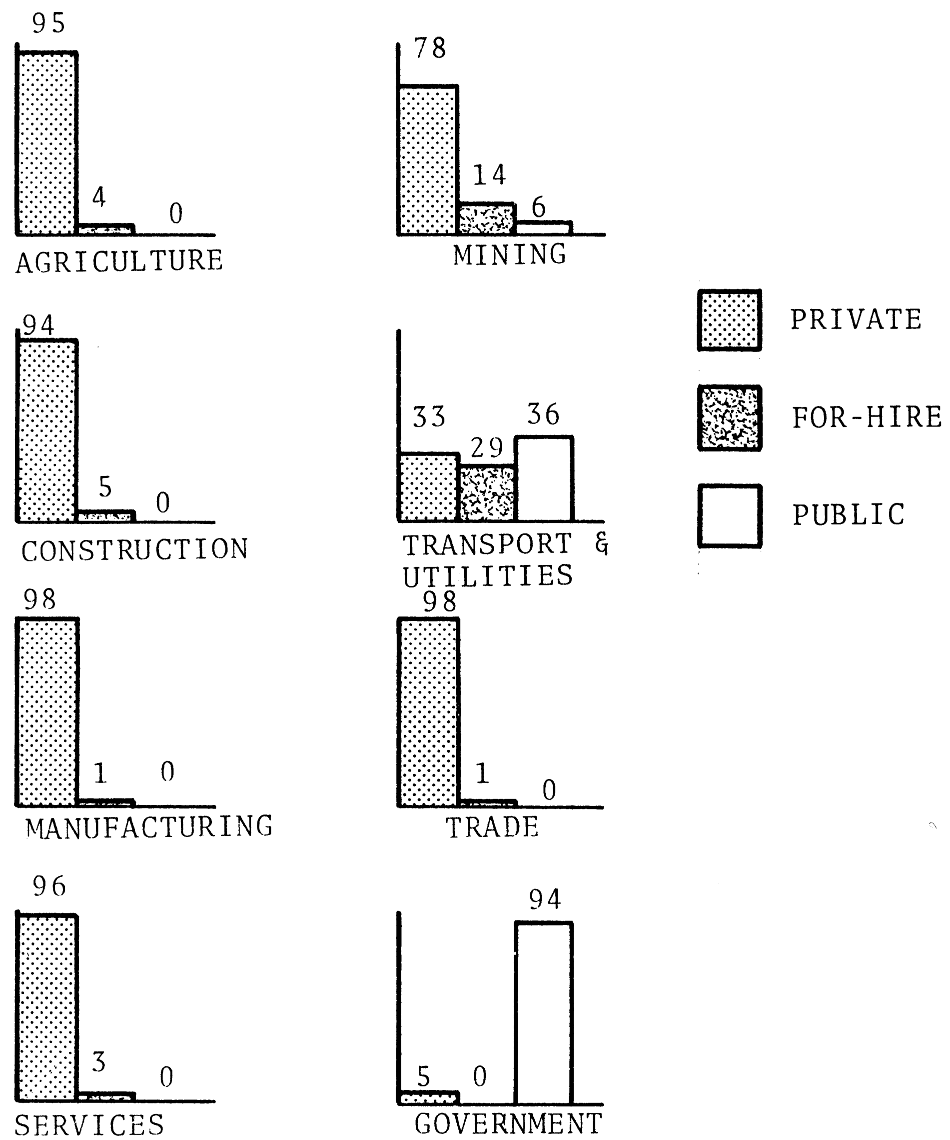


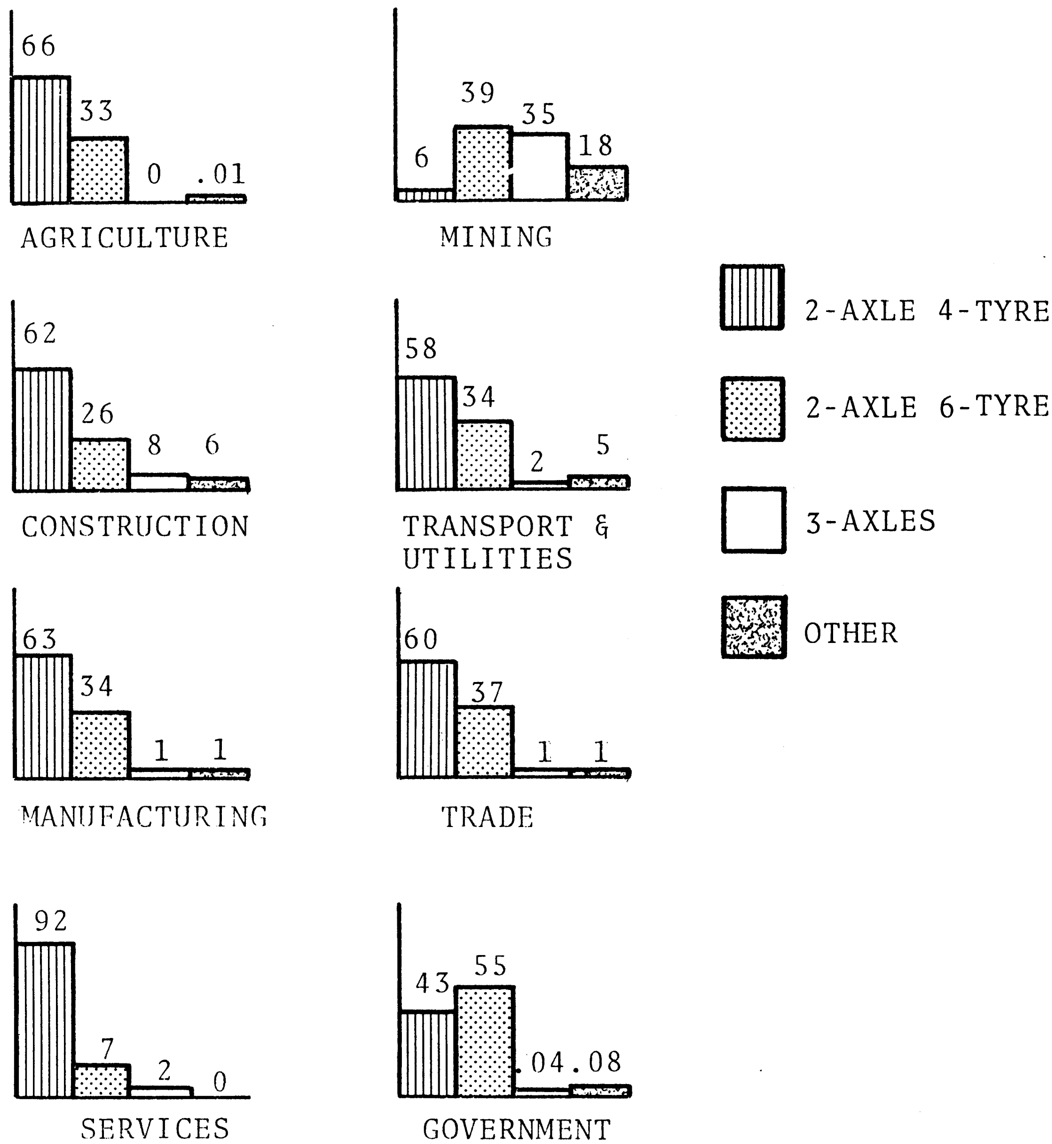
Table 6.1-6

The Percentage of Goods Vehicles

Operated by Type

Industry	Single Unit Vehicles: 2-Axle 4-Tire	Single Unit Vehicles: 2-Axle 6-Tire	Single Unit Vehicles: 3-Axle	Semi-Trailers & Combinations
Agriculture	78.4	21.0	.2	.4
Mining	15.9	36.9	31.1	16.1
Construction	71.8	23.3	3.5	1.4
Manufacturing	42.2	49.3	3.0	5.5
Transport, Comm. & Utilities	38.2	42.8	3.4	16.6
Trade	49.8	45.7	1.5	3.0
Services	76.2	21.7	1.5	.6
Government	54.3	42.8	1.2	1.7

Figure 6.1-4 Industry Trips by Percentage Vehicle Type



Next we consider some of the characteristics of daily goods vehicle transport patterns. Because it appears, as indicated previously, that a great many vehicles are operated in fleets of only one vehicle, the data to be presented may also be indicative of aspects of firms' daily transport patterns.

Table 6.1-7 gives the mean and standard deviation of the number of trips, deliveries, and tours made per vehicle by each industry group. These statistics suggest considerable variation in the manner and level of utilization of goods vehicles by different activities.

Relatively low trip and delivery frequencies per vehicle were found for agriculture, mining, and construction. The latter two activities were also the only industries for which the number of trips per vehicle substantially exceeded the number of deliveries. An important reason for these low trip and delivery rates may be that goods vehicles are used in mining, construction, and agriculture as part of the productive/extractive process and not just to deliver outputs or collect inputs. Consequently, truckload-size consignments are probably fairly common for these activities.

Table 6.1-7

Vehicle Trip, Delivery, and

Tour Frequencies

Industry	Trips/Vehicle		Deliveries/ Vehicle		Tours/Vehicle	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Agriculture	3.64	8.70	5.62	51.02	1.41	.86
Mining	8.95	5.35	5.65	5.35	2.86	2.54
Construction	5.30	5.03	2.75	9.75	1.47	.95
Manufacturing	17.35	21.35	20.86	39.52	1.84	1.30
Transport, Comm. & Utilities	13.41	16.75	14.09	48.21	1.42	.89
Trade	18.55	22.07	21.10	38.11	1.85	1.37
Services	43.16	44.64	64.81	129.29	4.28	4.33
Government	11.55	12.81	11.49	60.02	2.16	2.24

Apart from the above three activities, fairly high rates of daily trip-making in excess of 10 trips/vehicle appear to be a general characteristic of the provision of urban goods transport. Delivery rates per vehicle are slightly higher than trip rates, but the differences are fairly small in percentage terms for manufacturing, for-hire transport, communications, and utilities and trade.

Very high trip rates and even higher delivery rates were found for service industry vehicles. It seems likely that these statistics also reflect inherent characteristics of service activities and differences in goods vehicle trip purposes. Moreover, the very high average delivery rates raised the possibility that there had been considerable ambiguity in the definition of a "delivery" employed in the data collection and coding efforts. Inspection of trip records for service vehicles suggested that multiple service calls at the same destination locations had been coded as multiple deliveries. This conclusion also suggested that the delivery data for other activities might be somewhat less reliable than trip information because of similar definitional or interpretative problems.

The presence of considerable variation in vehicle trip and delivery rates within each industry group is indicated by the relatively large magnitude of their standard deviations about the mean rates/vehicle. For trips, the standard deviations are roughly 100% of the mean values. However, the standard deviations for the delivery frequencies per vehicle are, in general, much larger than the mean delivery rates. Closer inspection of the data, revealed that this was at least partially the result of extreme values of delivery rates for small numbers of vehicles in many of the industry groups. For example, the maximum number of deliveries per vehicle in the data was 232 for manufacturing, 283 for wholesale and retail trade, and in excess of 800 for for-hire transport.

Table 6.1-7 also provides the mean and standard deviation of the number of tours generated per vehicle per day. Both the level and the variability of the vehicle tour frequencies are considerably lower than trip and delivery frequencies for the same industry groups.

The histograms in Figure 6.1-5 show the percentage distribution of vehicle tour frequencies for manufacturing, for-hire transport,[2] trade, and total activity. The most striking feature of the tour frequency distributions is that the majority of vehicles operated by all four activity groups make only one tour per day. Roughly 20% of all

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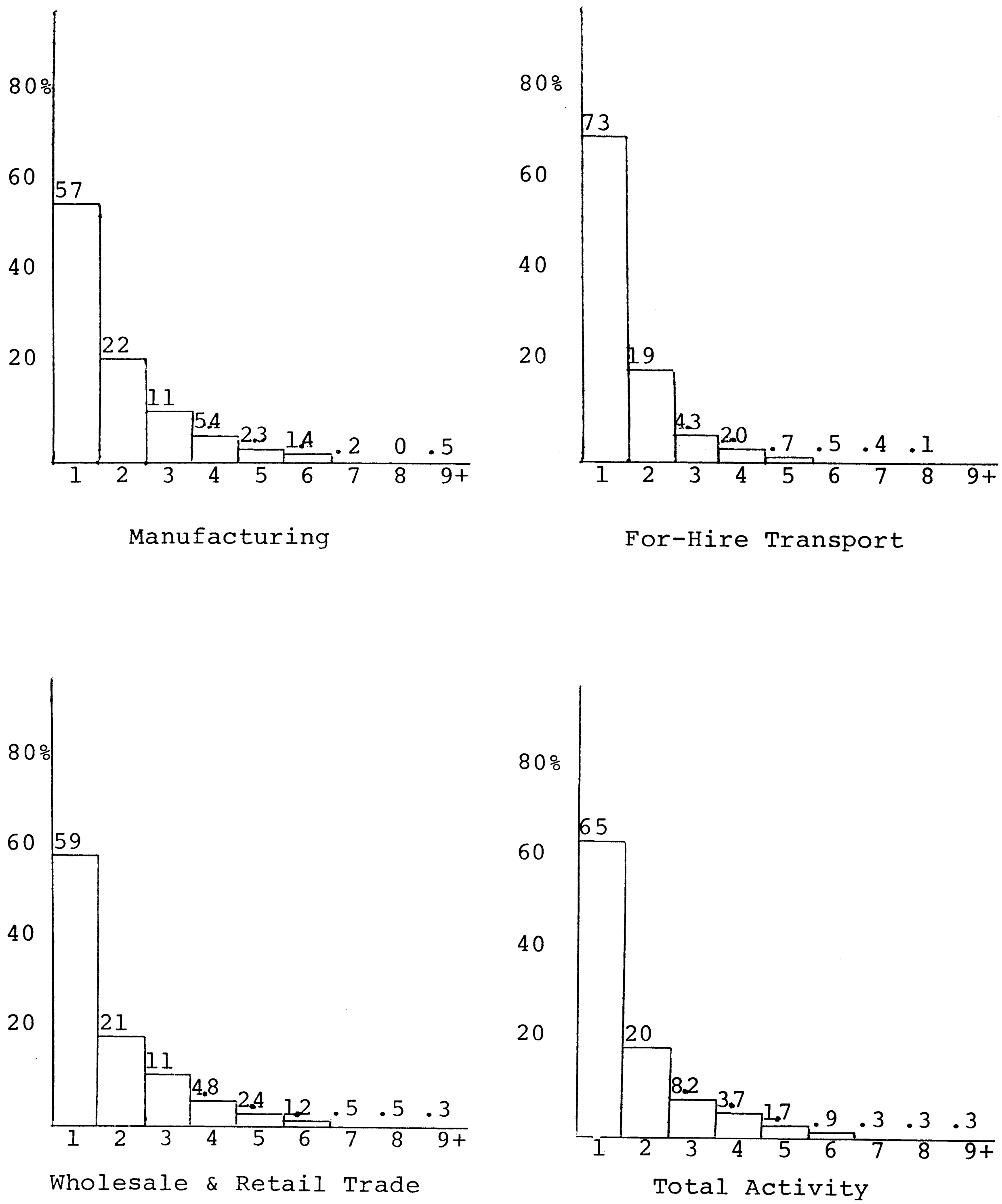
[2]This is a subgroup of transport, communications and utilities.

Figure 6.1-5

Vehicle Tour Frequency Distributions



vehicles in each group make two tours per day, 5-11% make three tours, and less than 5% make more than 5 tours per day. Although the frequency distributions are rather similar for the four groups, the incidence of 1-tour vehicle transport patterns is even higher for for-hire transport. This may be the result of the utilization of a greater percentage of large vehicles which can carry more consignments or of longer hauls which may preclude higher tour frequencies.

The prevalence of one-tour and two-tour goods vehicle trip patterns supports the hypothesis that firms attempt to increase the efficiency of their vehicle routing and scheduling decisions by achieving the highest possible degree of trip/delivery chaining subject to the binding constraints. This behavior tends to minimize the number of tours/vehicle.

We now turn to more direct measures of trip and delivery chaining. Table 6.1-8 presents estimates of the mean and standard deviation of the average and the maximum degree of trips and deliveries per tour for vehicles in the indicated activity groups. Table 6.1-8 provides the most obvious evidence of the high degree of trip chaining which was hypothesized to be an important characteristic of urban goods transport. Significantly, very high degrees of trip

Table 6.1-8

Measures of Trip & Delivery Chaining

Industry	Average Number of Trips/Tour/Vehicle		Average Number of Deliveries/Tour/Vehicle	
	Mean	Std. Dev.	Mean	Std. Dev.
Agriculture	2.58	7.50	3.97	33.90
Mining	3.11	4.41	1.97	4.01
Construction	3.60	4.58	1.87	7.06
Manufacturing	9.41	17.52	11.32	34.89
Transport, Comm. & Utilities	9.43	11.97	9.91	34.23
Trade	10.04	19.56	11.42	33.66
Services	10.08	24.22	15.13	35.18
Government	5.35	9.54	5.32	42.67

Industry	Maximum Number of Trips/Tour/Vehicle		Maximum Number of Deliveries/Tour/Vehicle	
	Mean	Std. Dev.	Mean	Std. Dev.
Agriculture	3.26	5.04	4.22	36.70
Mining	4.30	4.29	3.03	3.84
Construction	4.03	4.46	1.91	3.29
Manufacturing	11.33	17.10	15.59	32.43
Transport, Comm. & Utilities	9.70	12.63	11.12	37.73
Trade	13.33	18.97	16.45	32.24
Services	28.93	36.34	56.20	125.10
Government	7.03	9.19	8.65	47.77

and delivery chaining, i.e., averages in excess of 9 trips and deliveries per tour, were found for the manufacturing, transport, and trade sectors which, as noted before, together account for approximately 75% of all goods vehicle trips in the region. Note that there appears to be considerable variation in the degrees of trip and delivery chaining for the different industry groups. Because of major differences in the commodities produced, consumed, and transported by these industries; locational patterns; and the purposes to which goods vehicles are put, this variation is not surprising.

In order to explore the interrelationships of the various attributes of vehicle trip patterns, correlation matrices were computed. Table 6.1-9 gives the pairwise correlations between the seven indicated vehicle trip pattern attributes for vehicles operated by manufacturing, for-hire transport and trade.

The first attribute, vehicle size,[3] is positively correlated with the distance travelled and negatively correlated with the total number of trips and deliveries made for all three industry groups. One possible explanation for the fact that larger vehicles travel longer

[3]Vehicle size was a dummy variable taking integer values reflecting the rank order (from smallest to largest) of the vehicle types distinguished in the survey.

Table 6.1-9

Correlations Between Vehicle Trip Pattern Attributes

Manufacturing

	Veh. Size	Dist. Trav.	Total Del.	Total Trips	Max. # Trips/ Tour	Max. # Del./ Tour	# Tours
Vehicle Size	1.000						
Dist. Travelled	0.283	1.000					
Tot. Deliveries	-0.240	-0.075	1.000				
Total Trips	-0.257	-0.058	0.863	1.000			
Max. Trips/Tour	-0.214	-0.057	0.705	0.809	1.000		
Max. Del./Tour	-0.211	-0.085	0.826	0.671	0.835	1.000	
# Tours	-0.125	-0.019	-0.024	0.059	-0.129	-0.120	1.000

For-Hire Transport

	Veh. Size	Dist. Trav.	Total Del.	Total Trips	Max. # Trips/ Tour	Max. # Del./ Tour	# Tours
Vehicle Size	1.000						
Dist. Travelled	0.366	1.000					
Tot. Deliveries	-0.099	-0.011	1.000				
Total Trips	-0.234	-0.006	0.582	1.000			
Max. Trips/Tour	-0.219	-0.003	0.489	0.873	1.000		
Max. Del./Tour	-0.085	-0.019	0.931	0.472	0.518	1.000	
# Tours	-0.132	0.017	0.156	0.314	0.062	0.043	1.000

Wholesale and Retail Trade

	Veh. Size	Dist. Trav.	Total Del.	Total Trips	Max. # Trips/ Tour	Max. # Del./ Tour	# Tours
Vehicle Size	1.000						
Dist. Travelled	0.326	1.000					
Tot. Deliveries	-0.128	0.060	1.000				
Total Trips	-0.144	0.078	0.908	1.000			
Max. Trips/Tour	-0.111	0.049	0.806	0.854	1.000		
Max. Del./Tours	-0.119	0.012	0.878	0.782	0.915	1.000	
# Tours	0.011	0.104	-0.084	-0.033	-0.194	-0.165	1.000

distances but make fewer trips and deliveries is that they transport larger rather than more consignments.

Vehicle size is negatively correlated with the degree of trip and delivery chaining and the number of tours (except for the latter variable for trade). The carriage of larger consignments in large vehicles could also account for this relationship. Because of increased distances to pick-up and delivery points for larger vehicles, temporal constraints might preclude higher trip, delivery, and tour frequencies. However, the distance travelled is only weakly correlated with the other trip pattern attributes.

There is a very strong positive association between the total number of trips and the total number of deliveries especially for manufacturing and trade. There are also strong correlations between the degree of trip and delivery chaining. The relatively low correlations between trips and deliveries and between trip and delivery chaining for for-hire transport are likely to reflect the high incidence of multiple delivery, multiple collection, and multiple pick-up and delivery trips for this activity.

High correlations are also evident between total trips and the degree of trip chaining and between total deliveries and the maximum number of deliveries per tour. These should be judged cautiously because of the high percentage of 1-tour vehicle trip patterns. Nevertheless, the correlation coefficients may suggest that the degree of trip and delivery chaining may affect the level of transport operations even when other factors are taken into account. This would imply that constraints on trip and delivery chaining are significant determinants of goods vehicle traffic.

Correlation coefficients are, of course, very limited indicators of the complex interdependence of vehicle trip pattern attributes suggested by theory. While they fall short of providing a causal explanation for trip generation relationships, these observations were useful in formulating and interpreting the trip generation models which are introduced next.

6.2 The Determinants of Urban Goods Vehicle Trip Generation

In this section, the determinants of urban goods vehicle traffic are discussed and the theoretical basis of Chapter 3 and the analytical approach described in Chapter 4 are utilized to specify empirical models of goods vehicle trip generation. In this discussion, emphasis is placed on the statement of hypotheses governing the formulation of the models and on the choice of the variables and measures to be used in the empirical work.

The hypothesized set of structural equations for the industry trip generation model system are shown in Table 6.2-1a. Definitions for the variables appearing in the models are given in Table 6.2-1b.

The equations in the model system are formulated in terms of consignment, tour, and trip rates and activity densities rather than gross zonal totals for consignments, tours, trips, and activity variables. The formulation of the model equations in terms of rate variables instead of zonal totals is desirable because we are not interested in explaining arbitrary variations in the dependent variables that result from variation in zone size (Kern and Lerman, 1977). Since zonal data are grouped data, we would expect the error variances to be unequal for models based on zone totals (Maddala, 1977). Consequently, the least squares assumption of homoschedastic residuals "is more likely to be satisfied when rate rather than aggregate variables are used" (Douglas and Lewis, 1970b, p. 430). The hypothesized relationships embodied in the model equation will now be discussed in some detail; other econometric issues will be introduced later.

Table 6.2-1a

Trip Generation Equation System for Industry e

1.a. $D_i^e/A_i = c_{11}+c_{12}ACT_i^e/A_i+c_{13}V_i^e/A_i+c_{14}R_i^e+c_{15}LOC_i+c_{16}MDCH_i^e$

or

1.b. $TF_i^e/A_i = c_{21}+c_{22}ACT_i^e/A_i+c_{23}V_i^e/A_i+c_{24}R_i^e+c_{25}LOC_i+c_{26}MTCH_i^e$

2.a. $M_i^e/A_i = \begin{cases} 0 \text{ if } D_i^e \ngtr 0 \\ (D_i^e/A_i)/DCH_i^e, \text{ otherwise} \end{cases}$

or

2.b. $M_i^e/A_i = \begin{cases} 0 \text{ if } TF_i^e \ngtr 0 \\ (TF_i^e/A_i)/TCH_i^e, \text{ otherwise} \end{cases}$

3.a. $TA_j^{e*}/A_j = c_{31}+c_{32}^1ACT_j^1/A_j+\ldots+c_{32}^nACT_j^n/A_j+c_{33}LOC_j+c_{34}RT_j^e$

3.b. $TA_j^e/A_j = (\sum_k TF_k^e)(TA_j^{e*}/\sum_k TA_k^{e*})/A_j$

4. $T_i^e/A_i = M_i^e/A_i+TA_i^e/A_i$

TABLE 6.2-1b <u>Definitions of Variables</u>

D_i^e	=	The number of consignments picked up and delivered in all locations by industry e in zone i
TF_i^e	=	the number of trips generated in all zones by industry e in zone i for the purpose of picking up and delivering consignments
M_i^e	=	the number of tours generated by industry e in zone i
TA_j^{e*}	=	the observed number of trips provided by industry e attracted to all activities in zone j
TA_j^e	=	the predicted number of trips provided by industry e attracted to all activities in zone j
T_i^e	=	the total number of trips provided by industry e generated in zone i
ACT_i^e	=	a measure of the intensity of activity e in zone i (the number of employees for business activities and residential population for households)
V_i^e	=	the number of vehicles operated by industry e in zone i
R_i^e	=	the share of large vehicles operated by industry e in zone i
LOC_i	=	the location of zone i in terms of the inverse travel firms to the center of the region
$MDCH_i^e$	=	the average maximum number of deliveries per tour for vehicles operated by industry e in zone i
$MTCH_i^e$	=	the average maximum number of pickup and delivery trips per tour for vehicles operated by industry e in zone i
RT_j^e	=	the share of large vehicle trips provided by industry e which are attracted to all activities in zone j
A_j	=	the area of zone i
c_{mn}	=	coefficients to be estimated

Trip and Consignment Frequency

Equations 1a and 1b represent hypotheses concerning the determinants of transport provider consignment and trip frequency rates, respectively. As defined in Chapter 4, the transport provider consignment frequency is the total number of consignments picked up and delivered by industry e in zone i (i.e., on tours which originate at industry e's depots in zone i). Similarly, the transport provider's trip frequency is the volume of trips made in delivering and collecting consignments at non-depot locations by industry e in zone i. Therefore, the pickup and delivery trip frequency does not count one trip per tour which, under pure delivery or collection logistical arrangements, is not made for the purpose of goods collection or delivery. The volume of these omitted trips is the tour frequency which is determined subsequently in the causal structure.

The trip frequency equation (1b) is sufficient without equation 1a for the purposes of explaining trip generation as portrayed in the model system.[4] However, the delivery frequency equation has been included because it is part of an alternative method of estimating industry tour frequencies and because it is of interest in its own right.

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[4]Either 1a or 1b could be used (as in 2a or 2b respectively) to derive estimates of tour frequencies.

As reflected in equations 1a and 1b, the determinants of trip and delivery frequencies are hypothesized to include industry activity levels, vehicle supply in terms of numbers and capacity, the location of the transport provider, and the average maximum degree of trip or delivery chaining. Although trip and delivery frequencies differ in level, they are closely related and are thought to be determined by the same underlying factors. Consequently, identical models with differing coefficients have been postulated for these quantities, and the hypotheses pertaining to both are discussed together.

A positive relationship is hypothesized between transport provider activity levels and trip and delivery frequencies. This hypothesis follows from reasoning that greater activity levels will be correlated with (and possibly defined by) higher levels of goods purchases and sales from which the demand for consignments and goods vehicle trips is derived. Because of the substantial variation in the percentage of total urban truck trips provided by different activity groups and in their trip generation rates, it is suggested that the effect of activity levels upon these endogenous variables may also vary considerably from one activity to another.

One caveat concerning the relationship between trip and delivery frequencies and activity levels was suggested by the theory of transport pattern choices. If trip and delivery frequencies are limited by constraints on vehicle supply, capacity, and transport pattern duration, then these factors will predominate as causal variables, and industry activity levels may not be significant determinants of transport volumes.

The activity measures used in the empirical models were employment measures. Ideally, the most appropriate measures of industry activity would be volumes of purchases and sales of goods in need of transport to and from industry e in zone i to other locations. Together with data on logistical arrangements, these measures would be good indicators of the demand for transport. However, data of this type were not available, and the choice among alternative activity measures was severely restricted. Consideration was given to the utilization of measures of land use. However, measures of floorspace were unavailable, and measures of the land area devoted to different uses in each zone were thought to be too crude (and possibly misleading because of mixed land uses) to be of value in the modelling effort. Employment measures were thought to be much more sensitive measures of economic activity and, thus, were preferred for theoretical as well as for operational reasons.

A second major determinant of an industry's trip and delivery frequencies is hypothesized to be the supply of vehicles under its control and operation from each location. Decisions about vehicle ownership and leasing are of a longer-term nature and precede decisions about daily trip and consignment frequencies. Vehicle supply is important not only because it determines industry's capacity for transport activity, but because it is also intimately related to and reflective of prior (higher order) decisions concerning logistical arrangements. Specifically, higher levels of vehicle supply, hypothesized to be positively related to trip and consignment frequencies, will often be indicative of a commitment to or a preference for own-account transport of consignments rather than the utilization of for-hire transport by motorized modes or by rail. For this reason, vehicle supply may also serve to some extent as a proxy for freight consignment mode choice.

The mix of vehicle types by size may also be a determinant of consignment and trip frequencies, but unfortunately the direction of this effect is not clear. On the one hand, we might expect higher delivery rates to be correlated with the utilization of large-capacity vehicles. On the other hand, one would also expect that large vehicles would be operated by activities transporting larger consignments. Since at constant activity levels there should be an inverse relationship between consignment frequencies and average consignment sizes (which were not measured in the goods vehicle survey), there may be an offsetting effect.[5] For this reason, although it was felt important to include a measure of the percentage of large goods vehicles in equations 1a and 1b, no *a priori* judgement was made with respect to the hypothesized sign of its coefficients.

Large vehicles were defined as semi-trailers and other "combinations." These vehicles have significantly larger capacities than all other vehicles used in urban goods transport.

Another possible determinant of trip and delivery frequency is the location of the transport provider within the region and its accessibility to the destinations of goods consignments delivered (and the origins of goods consignments collected). Historically, local-market-oriented activities with high transport demands have sought relatively central locations within metropolitan areas. (Hoover and Vernon 1962). However, the post war suburbanization of population and employment facilitated by the car and the truck, resulted in the relocation of many of

[5]Recall that a negative correlation was found between vehicle size and vehicle consignment and trip frequencies.

the heaviest generators of goods and goods transport in non-central locations. There they could enjoy the benefits of larger amounts of industrial space at lower rents, good access to transportation facilities, freedom from traffic congestion, economies of scale in production/distribution from more modern and spacious plants, and proximity to the newly suburbanized residential markets.

Other firms retaining central locations may have developed a greater reliance upon for-hire transport rather than on own-account transport because of the difficulty in operating trucking and warehousing activities in congested and costly core locations. Alternatively, some firms in central locations may have chosen to operate delivery services from peripheral locations. For all of these reasons, it was hypothesized that consignment and trip frequency rates might be higher at locations of increased distance from the center of the region. However, it was thought that this effect would be primarily associated with the transport of outputs rather than the collection of inputs.

Location was thought to have an opposite effect on the frequency of goods vehicle trips associated with the consumption of inputs. One reason for this hypothesis is that the economies of scale in production, which are likely to be more common in non-central locations and which lead to higher trip frequencies for the shipment of output as output/employee ratios increase, may also be associated with larger purchases of inputs and thus fewer consignments attracted. Other reasons for higher rather than lower inbound consignment attraction rates in central locations will be discussed subsequently in the discussion of the determinants of trip attraction rates. Because it is thought that goods delivery is much more common than goods collection, the opposite effect of location on inbound consignment frequency was hypothesized to reduce, but not to offset the effect of location on overall trip and consignment frequencies.

There are a variety of reasons why accessibility to customers and suppliers could also be a determinant of consignment frequencies. One reason is that high accessibility may foster small and frequent transactions between buyers and sellers of goods (Hoover and Vernon, 1962). Another reason is the possibility of higher volumes of production and consumption per employee in more accessible locations. However, empirical evidence for the latter effect appears to be generally lacking for the intraurban context. Moreover, variation in goods production and consumption rates per employee might stem from so many sources such as variation in production functions, product mix, plant capacity, and location that it may well prove to be impossible to isolate the effect, if any, of accessibility. A further complication is that, for the reasons given previously, variation in consignments and trip frequencies resulting from variations in accessibility (or location) will not be observed if capacity limitations and other constraints restrict transport activity levels.

In spite of these difficulties, because location is only a crude measure of accessibility (Martin and Dalvi, 1975) and because location and accessibility might have differential effects upon trip and consignment frequencies, considerable thought was given to measures of accessibility other than location which could also be used in the empirical estimation of equations 1a and 1b. Unfortunately, insurmountable obstacles to the use of rigorous measures of accessibility, such as those described by Ben Akiva and Lerman (1977), were posed by the lack of data on alternatives and choices with respect to the sources, sizes, and commodity composition of goods purchases and sales, logistical arrangements, and consignments.

The central problem encountered in the construction of more conventional measures of accessibility concerned the choice of activity variables. Lacking the data noted above, no logical way was found for taking account of the differing (but unmeasured) goods producing and attracting propensities of all the activities served by each transporting industry. Obtaining suitable weights for activity employment variables would seem to require data and modelling of intraurban trade.

Another impediment to the construction of an unbiased measure of accessibility was the presence of mixed logistical arrangements. Because of these more complicated logistical strategies, there is a need to be concerned with both the accessibility of transporters to shippers for goods that are collected as well as the accessibility of transporters to receivers for goods that are delivered. Although it was thought that it might be possible to construct a composite accessibility index which would take account of the relative incidence of the various transport arrangements, data gaps concerning these arrangements precluded such attempts.

Lacking a better alternative, only a location variable enters in equations 1a and 1b. In the empirical models, the measure of location that is employed is the inverse travel time (in minutes) to the center of the region. This measure has the advantage that it reflects the supply of transport in terms of the level of service offered by the road network and thus is more likely to represent accessibility than other distance-based measures. Travel time was measured to the region's center, a choice supported by the roughly unimodal density profile of the region and the fact that non-central locations with good road access to the region center also tended to have good access to other areas. The inverse of travel time was preferred to travel time itself because it was hypothesized that its effects on consignment and trip frequency would tend to level off beyond some threshold distance from the region's center. Empirical tests subsequently showed that this choice was supported by the data.

The final variables appearing in equations 1a and 1b are the average maximum number of trips and deliveries per tour, respectively, for the transport provider. As discussed previously, these measures of trip chaining reflect the effect of various constraints upon transport pattern choices. Trip chaining is thought to be a major way in which transport providers increase the efficiency and volume of their operations. Consequently, higher levels of trip and delivery chaining are hypothesized to be positively related to trip and delivery frequencies.

Trip chaining may also be an important summary measure for factors omitted from these equations because of data or conceptual problems which, under certain circumstances, would be expected to affect trip and delivery frequencies. For example, trip chaining will reflect accessibility to the extent that accessibility limits the average maximum number of trips or deliveries made per vehicle tour. Similarly, trip or delivery chaining will reflect other factors such as consignment size or labor work rules to the extent that these are binding constraints. Although they are closely related, the average maximum number of trips or deliveries per vehicle tour is arguably more representative of relevant constraints than the average number of trips or deliveries per vehicle tour which is more likely to depend on actual demand levels. This is why the former rather than the latter measure was utilized in the trip and delivery frequency equations.

Tour Frequency

Equations 2a and 2b are identities which provide alternative estimates of transport provider tour frequencies. The equations represent the hypotheses that tour frequency is a simple function of either the consignment frequency and the average number of consignments picked up and delivered per tour, or, alternatively, the frequency of pick-up and delivery trips and the average number of pickup and delivery trips made per tour. Although they may give slightly different results, neither seems strongly preferable to the other in the absence of detailed data on the constraints determining the degree of trip and delivery chaining.

The theoretical justification for these identities is the explanation given for tour frequency as part of the proposed paradigm of trip chaining behavior. However, the divisors in equations 2a and 2b differ from that result in that the average number of trips and deliveries per vehicle tour has been substituted for the average maximum number of trips and deliveries per tour. It is not hard to see from the disaggregate formula given in Chapter 3, that the use of the latter measure would lead to a biased (low) estimate of aggregate zonal tour frequencies unless corrected for the number of behavioral units. Generally speaking, we would expect a close correspondence between these two measures of trip and delivery chaining, and it is not thought that this substitution constituted a conceptual sacrifice.

Pickup and Delivery Trip Attraction

The number of trips made by transporting industry e with destinations (or origins) at non-depot nodes in zone j, TA_j^{e*}, is given by equations 3a and 3b. Above this quantity is referred to as zonal trip attraction, but the term generation could also be used.[6] The important point is that here we are actually referring to the locations at which the trips are made rather than the number of trips made on tours emanating from a given location. Because of the high degree of trip chaining, it is TA_j^e* that is associated with most of the goods traffic observable at a given location in the region.

The basic hypothesis regarding trip attraction is that it is a function of the total level of pick-up and delivery trips made by industry e within the region, $(\sum_k TF_k^e)$, and the share, $[TA_j^e*/\sum_k TA_k^e*]$ which is "attracted" by all activities in zone j. The share is hypothesized to be a function of the location, intensity, and mix of activities in zone j, and the percentage of large vehicles used in delivering and collecting consignments from zone j. The latter variable is a proxy for consignment size.

Typically, in prior research, equations similar to 3a have been utilized as the sole basis for explaining goods vehicle trip generation in urban areas. At least superficially, equation 3a would appear to provide an alternative to equation 1b as a means of estimating the

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[6]As will be discussed subsequently, there will typically be equality of the number of trip origins and destinations. Since most of these trips are presumed to be delivery trips, the designation trip attraction may have slightly more intuitive appeal.

total number of trips (less tours), to be made within a region. Moreover, with survey data, $\sum_k TF_k^e = \sum_k TA_k^e*$ by definition. The fundamental issue is which, if either, equation to accept as the causal determinant of the level of transport activity. This is a problem of theory not of modelling, and, as such, we rely on the theoretical framework to resolve it.

The theory of urban goods transport demand presented in Chapter 3 points to equation 1b as the appropriate choice because it is the transport provider who determines the level of goods vehicle trips. For this reason, equation 3a is only used to determine the relative rather than the absolute level of trip attraction.

For purposes of estimation, it suffices to estimate equation 3a because $\sum_k TF_k^e$ and $\sum_k TA_k^e*$ cancel out. Equation 3b, which is an identity, ensures consistency for prediction and calculation of elasticities by requiring that $\sum_k TA_k^e = \sum_k TF_k^e$ when one or more of their determining variables change. An alternative procedure entailing direct estimation of a share model for $TA_j^e*/\sum_k TA_k^e*$ could also be used and would be appropriate for consistent "predictions" if negative right hand side estimates were obtained with ordinary least squares. A suitable approach would involve maximum likelihood estimation of a two-limit probit or other limited dependent variable model such as those described by Nelson (1974).

There are several important issues concerning the specification of equation 3a. One issue concerns the appropriate choice and representation of activity variables. Since each industry delivers its goods to many different activities and also may collect inbound consignments from different sectors, it is necessary that measures of the zonal intensity of the relevant sectors be represented in the trip attraction equations. Moreover, it seems reasonable to hypothesize significant variation in the trip attracting propensities of each sector both within each equation and across trip attraction equations for different transporting industries. This hypothesis governed the specification of the activity employment variables in the trip attraction models.

The specific choice of the activity variables which were to be used in each industry equation was based on a sectoral classification of activities in which employment in manufacturing, wholesale trade, retail trade, services, government, construction, and trucking and warehousing were distinguished. _A priori_ considerations suggested that these activities might have different trip attraction propensities. Empirical experience with a total trip generation model constructed during an early phase of this research also guided the initial specification of the activity variables. Empirical testing resulted in minor modifications to this classification scheme, as will be reported subsequently.

Another important hypothesis is that trip attraction rates (and shares) decline with increasing distance from the center of the region. One reason for this hypothesized effect stems from the oft-noted concentration of small firms in core locations (Vernon, 1957). Small firms typically have higher trip attraction rates than large firms (Starkie, 1967). Trip attraction rates may also be increased by external economies which, for small firms, are likely to be of greater consequence than internal economies of scale. External economies, which derive from the co-location of activities, are most prevalent in the densest areas of the region and may result in increased transport demand for inputs per unit of output.

A firm's demand for transport of inbound consignments is also likely to be influenced by levels of inventories of inputs. Firms which hold high inventories may require fewer goods vehicle trips. Since the price of space declines significantly with distance from the center of the region, lower consignment and trip attraction rates should be observed in distal locations where the land and space inputs needed to hold higher stocks are of lower cost and greater aveilability. Vernon (1957, p. 29) has taken this argument one step further by suggesting that new traffic problems will arise in the future because of a shift to small shipments as "wholesalers continue to move their warehousing operations to the periphery and as retailers grow increasingly insistent on smaller and more frequent deliveries to avoid the use of high-cost space for stocks."

It is easier for high rates of trip attraction to be provided in high density locations because of the technology of urban goods transport. At higher densities, it is relatively more efficient to serve multiple collection and delivery points. In these locations, market thresholds are of considerably smaller spatial extent (see Isard, 1956, p.271) than at lower densities of activity, and the distances between customers are relatively short, facilitating trip chaining. For consumers at locations where transport suppliers have only limited possibilities for serving more than one customer on the same tour, there may be lower levels of service and an incentive to receive larger shipments.

The last variable appearing in the trip attraction equation is the percentage of large truck trips attracted.

This variable is included as a proxy for consignment size which is hypothesized to have an inverse relationship with trip attraction rates. As indicated previously, it is expected that larger shipments will be transported in larger vehicles. Ordinarily, for forecasting purposes, an independent estimate of this variable would not be available. Since the purpose here is explanation rather than prediction, this was not a concern.

Total Zonal Industry Trip Generation

The total zonal industry trip generation rates are the sum of the respective industry tour generation rates and the pickup and delivery trip attraction rates as indicated by the identity, equation 4. Equation 4 also gives an explicit estimate of total zonal trip destinations, as this is, in general, virtually identical to total zonal trip generation due to the linked nature of goods vehicle trips.

An illustration of this point is provided by the co-efficient estimates of the regressions, shown in Table 6.2-2, of industry trip origins per zone acre versus trip destinations per zone acre and a constant term for the three major industry groups and total trips made by all industries (t-statistics are given in parentheses under each coefficient). The coefficients of the trip destination

Table 6.2-2

Results of Regressions of Trip Origin Rates

Against Trip Destination Rates

Explanatory Variables	Industry Trip Origins/Zone Acre			
	Manufact.	Transport	Trade	All Indust.
Constant	-.002 (-.418)	.003 (.800)	-.0002 (-.062)	.008 (.525)
Trip Destin./ Zone Acre	.999 (554.0)	.996 (851.1)	1.003 (827.2)	1.013 (703.9)
R^2	.998	.999	.999	.999
F	307000.	724000.	684000.	496000.

rates are all close to unity and are highly significant. The coefficients of the constant terms are near zero in magnitude and none are statistically significantly different from zero at the 90% confidence level.

This completes the discussion of the specification of the model system. The results of model estimation follow.

6.3 Model Estimation and Empirical Results

In this section, the results of the estimation of the trip generation model system equations and estimates of the endogenous variables determined by identities are presented and interpreted. We begin with a brief discussion of several important features of the model system with special reference to econometric issues posed by the trip generation equation system and the estimation procedures which were employed in obtaining parameter estimates.

6.3.1 Model Structure and Estimation

A distinctive feature of the approach taken in this research to quantifying the determinants of urban goods vehicle traffic is the utilization of a system of equations to represent trip generation relationships rather than a single equation model. Multiequation models are often required to represent complex theories and to obtain more detailed measurements of behavioral phenomena.

Apart from this justification, there are several important econometric reasons for the use of a multiequation approach to many modelling problems. One reason is that often there will be less specification error because of the extra consideration given to the determinants and functional form of each structural relationship and to the interrelationships of the endogenous variables. Another reason, particularly relevant here, is that when some of the endogenous variables are aggregates of other endogenous variables, estimation of separate equations for each endogenous variable should reduce aggregation bias. Finally, multiple equation models may avoid some estimation problems, sometimes making it possible, for example, to estimate linear rather than non-linear models.

Estimation of a general multi-equation model system, however, often presents econometric problems which cannot be overcome with single equation estimation procedures. For example, if the error terms are correlated across equations as might result from a simultaneous model structure,[7] ordinary least squares estimates of structural equations

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[7]In a simultaneous model, some endogenous variables also appear as explanatory variables in other equations.

will give biased and inconsistent parameter estimates (Hanushek and Jackson, 1977).

Since the particular model system postulated does not have a simultaneous structure, we seem to be on fairly safe ground in assuming that the errors are uncorrelated across the equations to be estimated and concluding that the application of ordinary least squares (OLS) estimation procedures to each equation is appropriate. A cautionary note is that, in making this argument we utilize the assumption made in the formulation of the equation system that one industry's transport activities are independent of other industries' transport activities in each location. This assumption is hard to defend because of the presence of for-hire transport. However, a crude empirical test was performed which failed to reveal any significant interdependence between for-hire transport and other industry trip frequencies.[a]

The model equations were estimated with zonal data for which 626 observations were available and were generally utilized. Despite the large number of observations, parameter estimates for some of the equations were found to

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[a]Specifically, when tested in the single equation trip frequency models, for-hire transport trip frequency was found not to be a significant determinant of the trip frequencies for the other activity groups.

be unstable in that they were very sensitive to the inclusion of a small number of observations characterized by extreme values in the data used for model estimation. This is, of course, always a danger of least squares estimation with extreme values in the data. Although consideration was given to the use of alternative estimators such as minimum absolute deviation and robust (iterative weighted least squares) regressions, these approaches were not attractive for hypothesis testing because of their largely unknown statistical properties (Maddala, 1977).

The main cause for the extreme values appeared to be sampling error. Because the objective was to obtain parameter estimates that would be meaningful and representative of the general case rather than a handful of observations, the approach taken was to delete the small number of outliers from the data used for estimation. As Maddala (op. cit., p. 90) has pointed out, the failure to discard outliers typically "produces meaningless results." Once this problem was recognized, an attempt was made to omit the outliers prior to model estimation in order to avoid compromising the validity of the regression statistics.

Model system equations were estimated for three industry groups and total activity. The three industry groups were manufacturing, for-hire transport, and wholesale/retail trade. The three industrial sectors chosen for the empirical analysis together account for almost 3/4 of all goods vehicle trips which were made in the region. Greater disaggregation of the analysis for these activities and the extension of the analysis to other industry groupings was considered, but rejected, in part because of potential problems with inadequate sample sizes at the level of traffic zones. Modelling unrepresentative estimates of zonal transport activity would lead to meaningless models and fallacious conclusions. Greater spatial aggregation was also considered but was rejected after limited experimentation because of what appeared to be considerable information loss and problems with multicollinear explanatory variables.

6.3.2 Transport Provider Trip and Delivery Frequency Model Results

Transport provider (pickup and delivery) trip and delivery frequency models were estimated for the three industry groups and total activity. Estimates of the full specifications of the delivery frequency models (equation 1a) are shown in Table 6.3-1. The t-statistics are given in parentheses below each coefficient estimate. For 600+ degrees of freedom, t-statistics greater than 2.3 are

Table 6.3-1

Estimates of Full Specifications of

Delivery Frequency Models

Explanatory Variables	Manufact.	Transport	Trade	All Activities
Constant	-.12845 (-2.38)	-.01501 (.62)	-.21374 (-2.12)	-1.51440 (-5.69)
Activ. Empl./ Zone Acre	.00153 (.28)	.11766 (3.01)	.0007 (.20)	.01160 (5.55)
Vehicles/ Zone Acre	15.1969 (23.14)	7.67889 (28.97)	15.7361 (50.55)	13.98760 (28.89)
% Large Vehicles	-.29255 (-.87)	-.29105 (-3.57)	-.64651 (-.95)	.51087 (.27)
Inverse Travel Time to CBD	-.03315 (-.03)	-.16196 (-.39)	-4.22598 (-2.57)	-9.22428 (-2.16)
Degree of Deliv. Chain.	.04369 (13.08)	.01920 (29.71)	.03672 (10.56)	.21848 (14.85)
R^2	.60	.77	.82	.68
F	186.2	414.5	561.4	269.0

significant at the 1% confidence level and t-statistics greater than 1.65 and 1.3 are significant at the 5% and 10% levels, respectively.

The regression results were very encouraging in that all of the coefficients except one had the signs suggested *a priori*, and most of the variables hypothesized to be determinants of consignment frequencies were found to be statistically significant. Inspection of the regression residuals failed to reveal any bias.

Perhaps the most important finding provided by the regression equations is that vehicle supply and the degree of delivery chaining are significant determinants of consignment frequencies. The coefficients of these variables are significantly different from zero at the 1% confidence level for each of the four equations.

The effect of activity levels is less clear cut. The activity variable coefficients are all of the correct sign, but for manufacturing and trade, they are close to zero in magnitude and not statistically significant. This may suggest that for these industries, other factors, such as the commitment to own-account transport and the available transport capacity as reflected in the number of vehicles in operation, are more important determinants of consignment frequencies. Alternatively, it may suggest that employment is not a sensitive indicator of the level of goods to be delivered and collected.

In the case of for-hire transport, the effect of activity levels is significantly different from zero. It would seem reasonable that for-hire transport activities are less likely to be constrained by vehicle supply and consequently more sensitive to activity levels which presumably reflect the demand for their services.

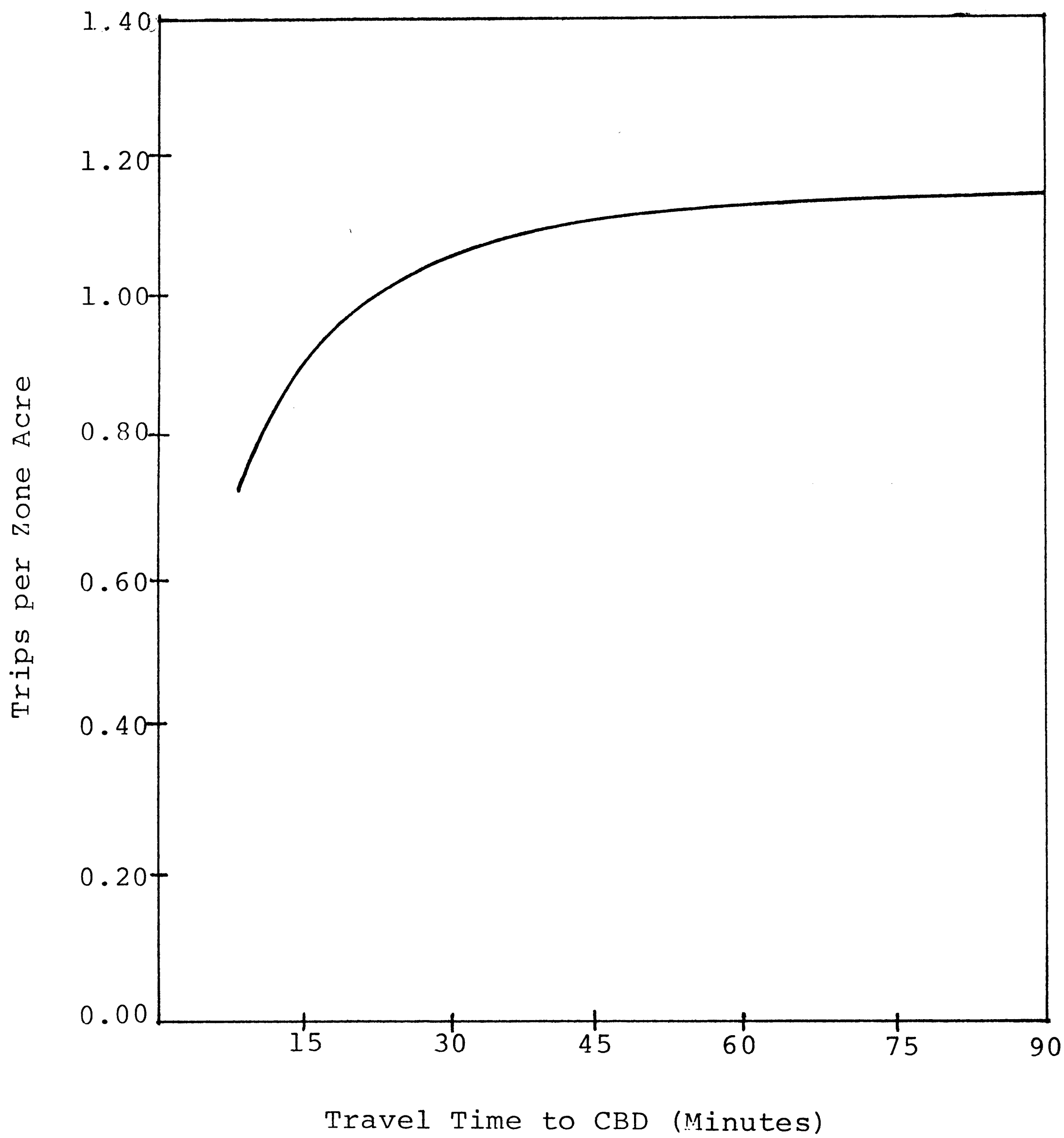
The coefficients of the vehicle size variable are negative for the three industry groups but positive for the total activity model. Previously, it was argued that the sign of this coefficient would be determined by the tradeoff between vehicle capacity and consignment size. The empirical results are not inconsistent with this view, but, for obvious reasons, they provide no affirmative basis for inference either. The percentage of large vehicles is only significant for for-hire transport. We might speculate that consignment sizes and vehicle loads would be more closely commensurate with vehicle sizes for for-hire transport than for other activities, but at best, this can only be considered an hypothesis for future examination with better data.

The coefficients of transport provider location as measured in terms of the inverse travel time to the center of the region all had the hypothesized negative sign, implying an increase in consignment frequencies with increasing distance from the CBD. However, only for trade and the total activity equations were the coefficients significantly different from zero. Empirical tests with other functional forms of travel time were conducted to determine if they would provide better results. However, in all cases the inverse travel time function outperformed simple linear and logarithmic functions of travel time.

Figure 6.3-1 illustrates the modelled relationship between the trade consignment frequency per zone acre (evaluated at the means of other explanatory variables) and travel time to the center of the region. Most of the variation in the delivery frequency rate is within 30-45 minutes of travel time to the center. In the central area, congestion is high and probably poses an impediment to both the location of enterprises with significant delivery operations and the scale of delivery operations of firms located there. Beyond this range the curve flattens substantially, and it appears that distance has only a neglible effect on delivery rates beyond the one hour isochrone.

Figure 6.3-1

Mean Trade Delivery Frequency Per Zone Acre as a Function of Travel Time to the CBD



Estimates of the final delivery frequency models are given in Table 6.3-2. These parameter estimates, which are quite similar to the corresponding coefficients in the full specifications, were used as the basis for computing elasticities of the dependent variables with respect to the independent variables.

Being free from the units of measurement, elasticities are especially useful indicators of sensitivity of the endogenous variables to changes in the independent variables.[9] Elasticities for the delivery frequency models, evaluated at the means of the explanatory variables, are shown in Table 6.3-3.

As is evident from the table, consignment frequencies are very sensitive to the supply of goods vehicles. This finding is intuitively logical and strongly supportive of the theoretical arguments made concerning the determinants of the firm's demand for goods transport. However, because vehicles which made no trips were not included in the data,

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[9]The elasticity of $Y = f(x)$ with respect to x, $E_x(Y)$, is defined as $(x/y)(\partial Y/\partial x)$. $E_x(Y)$ gives the percentage change in Y which results from a 1% change in x. Elasticities for complex functions such as those in the model system are easily derived by the application of elementary differential calculus. Elasticities also have important limitations as indicators of demand because they convey information about only one or two points on the demand curve.

Table 6.3-2

Regression Results for Final Delivery

Frequency Models

Explanatory Variables	Manufact.	Transport	Trade	All Activities
Constant	-.13208 (-3.10)	-.02066 (-1.07)	-.22532 (-2.26)	-1.49772 (-5.78)
Activ. Empl./ Zone Acre	NA	.11564 (2.99)	NA	.01157 (5.55)
Vehicles/ Zone Acre	15.1886 (24.49)	7.66737 (29.13)	15.73580 (50.96)	13.9959 (28.98)
% Large Vehicles	NA	-.28908 (-3.55)	NA	NA
Inverse Travel Time to CBD	NA	NA	-4.21006 (-2.59)	-9.24897 (-2.17)
Avg. Max. # Deliv./Tour	.04382 (13.15)	.01920 (29.73)	.03687 (10.64)	.21841 (14.85)
$\bar{R}^2$	.60	.77	.82	.68
F	466.8	518.8	936.9	336.7

Table 6.3-3 Delivery Frequency Elasticities

Variable	Manufact.	Transport	Trade	All Activities
Activ. Empl./ Zone Acre	NA	.054	NA	.068
Vehicles/ Zone Acre	.889	.762	.975	.957
% Large Vehicles	NA	-.085	NA	NA
Travel Time to CBD	NA	NA	.149	.122
Avg. Max. # Deliv./Tour	.499	.359	.389	.629

it is possible that the magnitude of this effect is overstated.

The level of the average maximum number of deliveries per tour also appears to have a large effect upon industry consignment frequency. In theory, the average number of deliveries per vehicle tour is determined by the interaction of the constraints of vehicle size and tour duration with factors such as consignment sizes and demand. Consequently, the statistical evidence from the models suggests that these constraints are important determinants of consignment frequency; the elasticities imply that a substantial increase in consignment frequencies would result from an increase in delivery chaining. At the same time, caution is warranted in accepting this interpretation because of the absence of information concerning precisely which, and in what ways, characteristics of consignment demand interact with the constraints in determining the average maximum number of deliveries per tour.

Estimates of the full specifications of the transport provider (pickup and delivery) trip frequency models are shown in Table 6.3-4. All the coefficients of the explanatory variables have the hypothesized signs. As would be expected from the close relationship between trip and consignment frequencies, which were hypothesized to be

TABLE 6.3-4

Estimates of the Full Specifications of

the Trip Frequency Models

Explanatory Variables	Manufactur.	Transport	Trade	All Activities
Constant	-.09985 (-2.98)	-.03721 (-2.36)	-.17653 (-2.78)	-1.40835 (-7.79)
Activity Employment/ Zone Acre	.00674 (1.98)	.07176 (2.93)	.00125 (.57)	.00656 (5.36)
Vehicles/ Zone Acre	10.86070 (26.53)	6.61191 (38.78)	13.36580 (70.16)	11.47200 (40.13)
% Large Vehicles	-.22240 (-1.08)	-.21888 (-4.28)	-.67324 (-1.62)	-.36314 (-.33)
Inverse Travel Time to CBD	-.26760 (-.46)	-.05104 (-.20)	-3.25934 (-3.24)	-6.76011 (-2.71)
Avg. Max # PUD Trips/Tour	.04699 (14.73)	.02484 (14.57)	.03416 (10.17)	.20510 (12.42)
$\bar{R}^2$	.68	.81	.90	.78
F	265.0	514.1	1065.9	455.0

generated by the same mechanism, there is a very close relationship between the estimation results in Table 6.3-4 for trips and those in Table 6.3-1 for consignments. For this reason, the trip frequency equations support the same conclusions as the consignment frequency equations.

Overall the trip frequency models fit the data somewhat better than the consignment frequency models; the coefficients of determination are higher in the former than for the latter for each of the four equation pairs. This may be the result of the greater incidence of extreme values in delivery rates than in trip rates in the survey data. Alternatively, it may reflect the considerable variation we would expect in the characteristics of consignments.

Inspection of Table 6.3-4 shows that the number of vehicles in operation and the average maximum number of trips per tour are statistically significant determinants of industry trip frequencies for each of the three industries and for total activity trips. Note that the coefficients of the number of vehicles operated per acre are somewhat higher than for the delivery equations. This reflects the fact that, as documented in section 6.1, delivery frequency rates are higher than trip frequency rates.

Activity employment levels were significant for all activities except for trade. In this regard, the results differ from the consignment frequency equation. Although manufacturing employment levels did not affect consignment frequency rates, they apparently are significant determinants of manufacturing trip frequencies. Another of the few differences between the two sets of equations is that the coefficient of the percentage of large vehicles operated is significantly different from zero at approximately the 10% confidence level in the wholesale/retail trade trip frequency equation while it was not significant in the corresponding consignment frequency equation.

Estimates of the coefficients of the final versions of the industry trip equations are given in Table 6.3-5; the elasticities of the industry trip frequency rates with respect to the indicated explanatory variables (evaluated at their means) derived from these coefficients are displayed in Table 6.3-6. These elasticities are very similar in magnitude to the elasticities of industry consignment frequency rates with respect to the same explanatory variables.

Taken in concert, the results from the consignment and trip frequency models provide strong statistical evidence of

TABLE 6.3-5

Regression Results for the Final

Trip Frequency Models

Explanatory Variables	Manufactur.	Transport	Trade	All Activities
Constant	-.11281 (-4.19)	-.03901 (-3.06)	-.18858 (-3.00)	-1.42021 (-8.01)
Activity Employment/ Zone Acre	.00660 (1.98)	.07113 (2.94)	NA	.00658 (5.39)
Vehicles/ Zone Acre	10.7960 (26.63)	6.60805 (39.05)	13.37020 (70.66)	11.46620 (40.21)
% Heavy Vehicles	NA	-.21827 (-4.28)	-.67324 (-1.62)	NA
Inverse Travel Time to CBD	NA	NA	-3.21184 (-3.23)	-6.74263 (-2.70)
Avg. Max. # PUD Trips/Tour	.04718 (14.82)	.12485 (14.59)	.03437 (10.26)	.20516 (12.43)
$\bar{R}^2$	.68	.81	.90	.79
F	441.7	643.6	1772.6	569.4

Table 6.3-6 Trip Frequency Elasticities

Variable	Manufact.	Transport	Trade	All Activities
Activ. Empl./ Zone Acre	.058	.041	NA	.051
Vehicles/ Zone Acre	.846	.824	1.02	1.03
% Large Vehicles	NA	-.081	-.014	NA
Travel Time to CBD	NA	NA	.140	.117
Degree of Trip Chain.	.540	.426	.341	.698

the different substantive conclusions that are reached by modelling the freight traffic operations of transport providers rather than with alternative modelling schemes. In prior research, less meaningful groupings of trips were modelled and the model formulations made it difficult, if not impossible or illogical, tc include measures of transport supply in the specifications employed. Were it not for the almost total absence in prior work of statistical evidence of the importance of transport supply as a determinant of urban goods traffic, it would seem less appropriate to belabor the point that the number of goods vehicle trips observed in a metropolitan area is likely to be closely related to the number of goods vehicles in operation.

These findings also have implications concerning the mechanism and the time-scale which are associated with changing levels of urban goods transport activities. The importance of vehicle supply suggests that longer-term decisions on logistical arrangements and vehicle ownership and leasing are among the principal determinants of goods vehicle traffic. This finding may also suggest that trip and consignment frequencies may often be determined by constraints upon the provision of pickup and delivery services.

The presence of constraints upon the levels of industry consignment and trip frequencies could also account, at least in part, for the low elasticities with respect to employment levels. Another reason for these results may be that at higher activity levels, industries may make larger sales (and purchases) which result in a lower rate of growth in trip and delivery frequencies as a function of employment levels.

One possible interpretation of the elasticities of trip and delivery frequency rates with respect to vehicle supply is that their magnitudes provide a crude indication of the percentage of transport capacity which is utilized by each industry group. An elasticity of 1 would imply near-capacity or capacity-constrained utilization of goods vehicles. Because consumers of retail goods often collect their purchases on shopping trips, in constrast to other industries there may be less of a need for retail trade to provide high levels of service for deliveries or have extra vehicle capacity for periods of peak demand. This difference in logistical arrangements may account for the higher elasticity for trade than for manufacturing and for-hire transport.

The finding that, all other factors being equal, trade employment is not a significant determinant of trade trip and consignment frequency is consistent with the reasoning above; this also represents a departure from prior research findings and conventional planning wisdom.

For manufacturing and for-hire transport, the trip frequency elasticities with respect to vehicle supply are .846 and .824, respectively. These measurements suggest that, in general, vehicle supply does not provide a capacity limitation upon their transport operations; rather, it suggests that there is some extra capacity which may also be associated with higher levels of service in the form of more rapid and reliable deliveries. This interpretation also fits with the finding that activity levels are significant determinants of transport provision by these industries. If vehicle supply does not appear to place a capacity limitation upon goods transport operations for manufacturing and for-hire transport, then other constraints such as those which determine the degree of trip chaining may. Note that the elasticities of trip and delivery frequencies are higher for these two industry groups than for wholesale and retail trade.

Another major substantive difference between these findings and those obtained from other approaches is that trip and delivery chaining, which both theory and data tabulations indicated were imporatnt features of urban goods transport, were found to be significant determinants of trip and consignment frequencies. This finding is particularly important because many transport, economic, institutional, and governmental policy and regulatory factors that may influence levels of goods vehicle traffic will do so largely through the impact they have as determinants of trip and delivery chaining. If we can achieve a better understanding of the determinants of trip and delivery chaining, then we should be able to improve our estimates of the direction and the magnitude of the effects of transport policies upon the pattern and level of goods vehicle traffic in large metropolitan areas.

6.3.3 Tour Frequency Estimates

Estimates of tour frequency by industry and for all activities combined were derived from the estimated trip frequency equations just presented. The trip frequency equations were employed rather than the consignment frequency models because the former were preferable in terms of theoretical consistency, statistical significance, and mean square error of the estimated versus actual measures of industry transport operations. Utilizing equation 2b, the estimated right-hand sides of these models were divided by the indicated measures of trip chaining to obtain "predicted" tour frequencies.

These predictions were then compared with the observed data. Simple correlations of estimated versus actual tour frequencies were .849 for manufacturing, .868 for for-hire transport, .956 for wholesale and retail trade, and .893 for total activity.

Since correlation coefficients do not take account of systematic differences in the mean of the predicted and observed tour frequencies, the latter were regressed against the former plus a constant term. Results of these regressions are shown in Table 6.3-7.

Although these equations evidence a strong statistical relationship between predicted and observed tour frequency, they also indicate bias in the estimates in the form of systematic differences between these quantities. A test of the hypothesis that the coefficients of the estimated tour frequency rates are significantly different from 1 was provided by the application of t-tests. The coefficients for the transport, trade and total activity models were found to be significantly different from 1 at the 1% confidence level although the coefficient for manufacturing tours was not. No clearcut explanation for why the model overestimates tour frequency is readily at hand, but it is possible that this is the result of extreme values which may

TABLE 6.3-7

Regressions of Actual Versus Estimated

Tour Frequency Rates

Explanatory Variable	Actual Tour Frequency/Zone Acre Manufact.	Transport	Trade	Total Activity
Constant	-.01138 (-2.93)	.00050 (.26)	-.02024 (-3.08)	-.03169 (-1.76)
Estimated Tour Frequency/Zone Acre	1.00927 (39.92)	.77328 (43.53)	.90941 (80.58)	.93060 (49.27)
$\bar{R}^2$	.72	.75	.91	.80
F	1593.6	1894.7	6542.9	2427.5

tilt the regression lines. Alternatively, it may be the result of aggregation bias.

An obvious consequence of the tour frequency identity is that every determinant of trip and delivery frequency is also a determinant of tour frequency. Moreover, it is easy to see by elementary calculus that, with the exception of the degree of trip chaining, the elasticities of the tour frequency with respect to the explanatory variables are identical to the elasticities of the trip frequency rate (or delivery frequency rate) with respect to the same variables. The elasticity of the tour frequency rate with respect to the average maximum number of trips per tour or the average number of trips per tour cannot be computed without making an assumption about the interrelationship of these quantities since they are obviously not independent. We assume, therefore, that they are related by a multiplicative constant (a different one for each industry) whose value is determined by dividing their respective zonal means. This enables us to compute elasticities with respect to the average maximum degree of trip chaining, which, along with the other elasticities, were evaluated using the trip frequency results at the means of the independent variables. These are given in Table 6.3-8.

TABLE 6.3-8

Tour Frequency Rate Elasticities

Explanatory Variable	Manufactur.	Transport	Trade	All Activities
Activity Employment/ Zone Acre	.058	.041	NA	.051
Vehicles/ Zone Acre	.846	.824	1.02	1.03
% Large Vehicles	NA	-.081	-.014	NA
Travel Time to CBD	NA	NA	.140	.117
Avg. Max. # PUD Trips/Tour	-.554	-.590	-.875	-.381

As would be expected, the elasticities of tour frequency with respect to the degree of trip chaining are negative in sign and relatively large in magnitude. They are smaller than -1, however, because of the offsetting effect of the degree of trip chaining on trip frequency. Moreover, it is the variation in the effects of trip chaining on trip frequency that leads to the variation in the elasticities of tour frequency with respect to the average maximum number of trips/tour.

6.3.4 Trip Attraction Equation Results

The results of estimation of the coefficients of the trip attraction equations for the three industry and total activity groups are presented in Table 6.3-9. The results obtained were thought to be quite satisfactory in that the model relationships and the coefficients were all highly significant. The four equations fit the data reasonably well, and the coefficients of the significant variables all had the correct sign. Plots of the residuals of these equations appeared to be unbiased.

These equations were selected after tests were made with two or three closely related variants of the specifications ultimately judged best. The results of the estimation of the other model variants contributed little in

TABLE 6.3-9 Zonal Trip Attraction Models

Explanatory Variables	Manufactur.	Transport	Trade	All Activities
Constant	-.17470 (-4.64)	-.18378 (-6.41)	-.28863 (-4.62)	-.42257 (-2.38)
Manufactur. Emp. Density	.01795 (4.60)	.02405 (5.48)	.04510 (6.86)	.18024 (20.50)
Wholesale Emp. Density	.14098 (20.33)	.15375 (13.37)	.12419 (7.88)	.72932 (19.78)
Retail Emp. Density	.03294 (19.46)	.03906 (28.02)	.03955 (13.89)	.13497 (17.15)
Trucking and Warehousing Emp. Density	.13569 (1.49)	.66194 (8.44)	.84148 (5.27)	3.03556 (7.60)
Railroad Trans. Emp. Density	NA	.17566 (3.26)	NA	NA
Government Emp. Density	.01050 (4.56)	.00365 (2.05)	.01064 (2.78)	.02746 (2.62)
Other Emp. Density	.00943 (10.05)	NA	.00961 (6.03)	.03969 (10.16)
Population Density	.03278 (21.54)	NA	.02650 (10.40)	.08124 (11.61)
Inverse Travel Time to CBD	4.14489 (6.24)	7.47393 (14.15)	19.39850 (17.54)	32.63260 (10.67)
% Large Vehicle Trips	NA	NA	NA	-5.46739 (-2.21)
$\bar{R}^2$	.87	.83	.81	.89
F	514.9	431.8	321.5	535.1

the way of insight into the determinants of goods vehicle trip attraction and had very little impact on the final specifications. Consequently, rather than describe these other results in detail, only the conclusions will be summarized.

One conclusion was that the percentage of large vehicle trips attracted was not significant determinant of trip attraction rates for manufacturing, for-hire transport, or trade. This variable, which would typically not be available in a forecasting context, was included as a proxy for the average consignment size delivered or collected. It was found to be a significant determinant of total activity trip attraction, and thus it appears in that equation with the hypothesized negative sign.

Another preliminary result was that railroad transportation employment was found to be a significant determinant of for-hire transport trip attraction. This variable was not included in the initial specification. Subsequently, it was thought that it might capture significant intermodal and interregional trade linkage effects on intraurban goods vehicle trip attraction. However, it was not significant in the other three equations.

Construction employment was also tested as an additional explanatory variable but was either not significant or had the wrong (negative) sign. A possible explanation for these results is that most construction trips are attracted to construction sites whose intensity may be poorly reflected by zonal employment measures; these sites may also tend to be fairly dispersed and thus correlated with other activity levels. The last important difference between the initial and final versions of the trip attraction equations was that "other" employment and population were not found to be statistically significant determinants of for-hire transport trip attraction.

A final test of the initial specification involved alternatives to the inverse travel time as the functional form for the location variable. Both travel time and the log of travel time were tried, but neither fit the data as well. Therefore, the initial specification was not changed.

We now consider the major findings which emerged from the trip attraction models. Perhaps the most important finding is the importance of the mix and level of activities as determinants of goods vehicle trip attraction. Because the activity variables are measured in the same units, we can assess the relative trip attraction effects of different activities by comparing their coefficients.

In the case of manufacturing trips, wholesale employment and for-hire transport employment have high trip attraction rates. This accords with the inbound and outbound linkages typically associated with manufacturing activities. Since manufacturing activities typically maintain linkages which cross regional boundaries and extend over long distances, this could easily account for the relatively large magnitude of the trucking and warehousing employment coefficient relative to the other coefficients in the manufacturing equation.

The coefficient of population per zone acre is also quite high. In fact the coefficient estimates imply that an increase of one resident per zone acre would have the same effect on the attraction of manufacturing trips as an increase of one retail employee per zone acre. Evidence obtained by Wilbur Smith and Associates (1969) indicated that more than 40% of all goods vehicle trips made in three medium-sized urban areas were attracted to residential land uses. Therefore, this result from the trip attraction equations is not regarded as anomalous. Rather, we might speculate that many manufacturers may also function as retailers in their own regional markets and sell directly to customers. This would account for the high trip attraction rate attributed to residential population.

The relatively low rate for retail employment density may reflect a number of factors. One possibility is that manufacturers are much more likely to sell their output to wholesalers than to retail outlets. Another possibility is that manufacturers purchase their inputs directly from other industries rather than from retailers.

Although there is some similarity between the coefficients of the activity variables for for-hire transport and manufacturing, the coefficient of trucking and warehousing employment is much larger for for-hire transport. This pattern of intraindustry or interdepot trucking operation is further illustrated by the linkage between truck and rail transport which is evidenced by the relatively large coefficient of the railroad transport employment density variable.

For the trade trip attraction equation, the coefficients of the activity variables are quite similar to those for manufacturing and transport. However, for trips made by wholesale and retail trade, it is inferred that trucking and warehousing activity has an even higher attraction rate per employee than for other trip types and for other employment categories. It would have been interesting to have explored this further to see if it could be attributed to the scale of warehousing activities rather than to the scale of for-hire trucking operations but unfortunately, the employment data could not be disaggregated further.

The coefficients of the total activity model are, as one would expect, considerably larger in magnitude than those for the industry equations because the dependent variable is greater than the sum of the dependent variables for the industry equations. Even more variation in the coefficients of the activity employment variables is evident in the total trip model. Trucking and warehousing employment has the coefficient of the greatest magnitude, attracting more than 3 trips per employee/zone acre. As in the manufacturing and trade equation, wholesaling employment has the second highest coefficient. From the coefficient estimates we see that each wholesaling employee attracts roughly 3 times as many trips as each manufacturing employee and more than 4 times as many trips as each retail employee, holding all other factors constant.

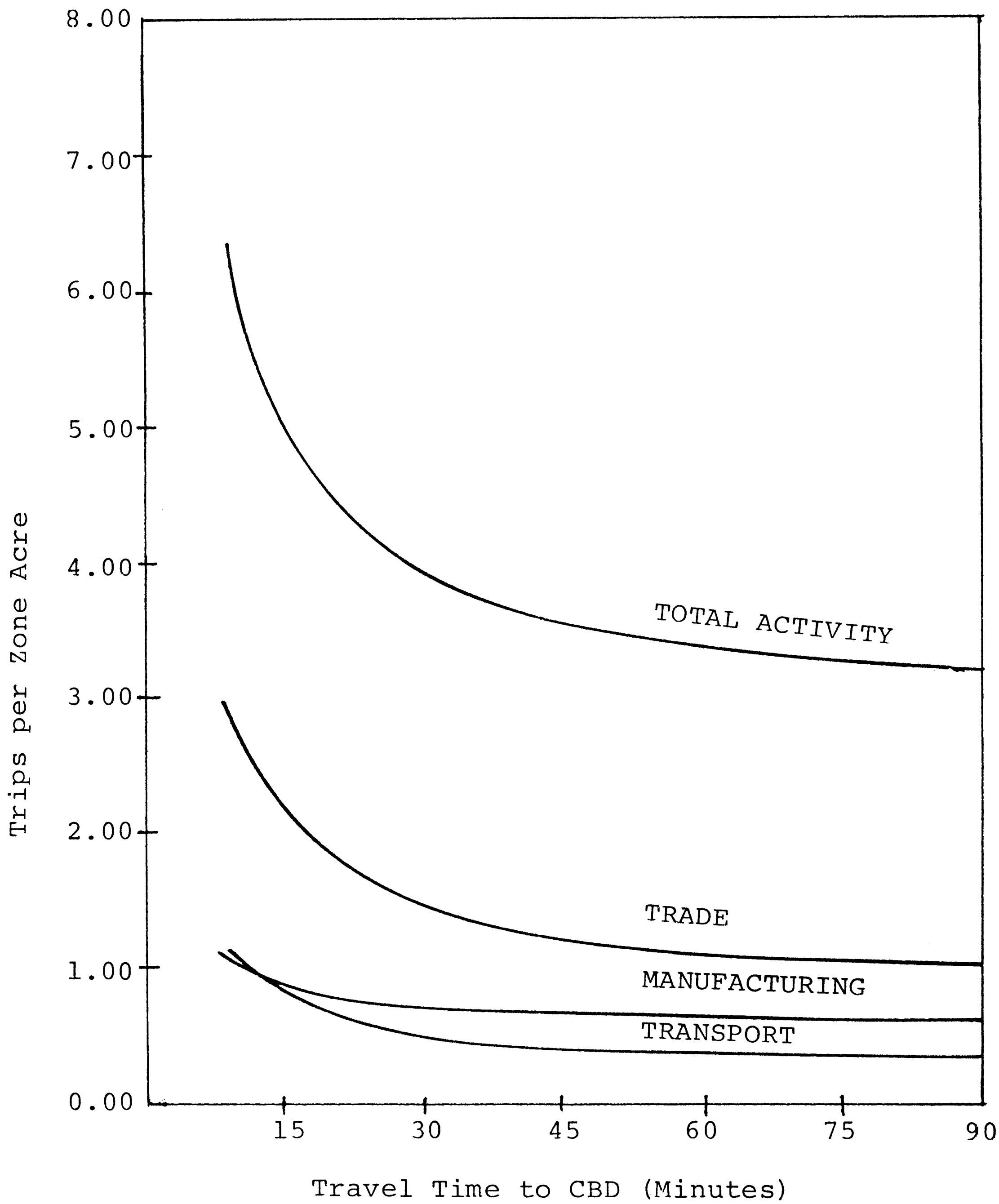
Another important finding from the trip attraction equations is that location is a significant determinant of all four trip attraction rates. Because the coefficients of the inverse travel time variables are positive, trip attraction rates decline with increasing distance from the region's center. In section 6.2, it was hypothesized that a wide variety of factors would lead to this result. Among the major factors discussed were (1) the prevalence of smaller firms and external economies in central locations; (2) locational variation in the supply and price of the space needed to hold inventories; and (3) the technology of urban freight transport which is characterized by multi-destination tours.

The relationship between trip attraction rates and location for each equation is graphed at the mean values of the other relevant explanatory variables in Figure 6.3-2. The most rapid declines in trip attraction rates with increasing distance are for the total activity and trade trip groups. In contrast, the curves relating the trip attraction rate and travel time to the CBD for manufacturing and transport are closer to straight lines and slope downward more gently.

Most of the locational variation in trip attraction rates occurs within 45 minutes of the center of the region. Unlike trip frequency rates, trip attraction rates indicate the locations of the origins and destinations of most goods vehicle trips. Therefore, it is evident from the results shown in Figure 6.3-2 that the highest rates of goods vehicle trip generation are found in the most densely settled and congested portions of the region. This result

Figure 6.3-2

Mean Industry Trip Attraction per Zone Acre as a Function of Travel Time to the CBD



is not inconsistent with the finding that trip frequency rates increase with increasing distance from the center of the region. In fact, the higher trip attraction shares found in central locations may be a consequence of the same economic forces which made it more costly and less efficient for central locations to be used for depots at a time when large-scale roadbuilding and widespread utilization of motor vehicles for urban freight transport reduced the cost of delivery services.

From the theoretical arguments made in section 6.2 previously, the role of the trip attraction rate equations in the equation system was as the determinant of the zonal shares of regional trip levels. Because of the equivalence of industry pickup and delivery trip frequencies and trip attraction in the survey data, we have been able to discuss the actual trip attraction rates by using equation 3a directly rather than equation 3b. Moreover, the same discussion points pertaining to trip attraction rates also pertain to the determinants of zonal trip attraction shares.

However, in order to derive meaningful elasticities of trip attraction rates with respect to their determinants, we need to take account of the relationship specified in equation 3b. This is not entirely straightforward because we lack needed basic information on the interdependence of levels of different activities within and across regional boundaries. Given the model structure, it may be observed that an increase in the share of trips attracted to zone j will necessarily reduce the share of trips to other zones. Obviously, there is no logical reason why an increase in employment in an activity in zone j should result in fewer trips to other zones if employment levels in other zones do not change. Also, the effects of an increase of employment in an activity in zone j upon total trip frequency will only come through increases in some determinant of trip frequencies in j and in other locations. This is one fairly obvious reason why an adequate forecasting procedure for urban goods traffic will have to take account of the spatial and interindustrial interdependence of activities within an equilibrium framework.[10]

If, however, we assume that an increase in some determinant of the trip attraction share stems from a decrease or corresponding shift in that determinant from other zones, we can use the model equations to compute elasticities of total trips attracted per zone acre for a hypothetical average zone j for which there is a reasonable interpretation.

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[10]One means of obtaining equilibrium activity forecasts would use an input-output model if one were available.

The trip attraction rate elasticities are given in Table 6.3-10. The computation and interpretation of the elasticities is greatly aided by noting from inspection of equation 3b that the effect of an increase in any determinant of average zonal trip frequency rates will have the same percentage impact on the trip attraction rate as on the trip frequency rates because the trip attraction shares will not change. Perhaps the most obvious point regarding the trip attraction rate elasticities is in their numerical reflection of the model assumptions showing that the elasticities with respect to determinants of trip frequencies have the largest magnitudes.

The elasticities of the trip attraction rates with respect to zonal variables indicate the percentage increase in the industry trip attraction rate per zone acre for a 1% increase in the indicated variable in zone j under the assumption that the total level of tripmaking by that industry in the region does not change. For each column, the elasticities with respect to the different employment variables and population provide a crude picture of intersectoral interdependence in terms of own-account transport linkages between the various sectors and the indicated column activity group. Inspection of these zone j variable elasticities reveals some different information than that provided by the estimated coefficients. For

TABLE 6.3-10

Trip Attraction Rate Elasticities for

Industry Trips Attracted to Zone j

Explanatory Variables	Manufactur.	Transport	Trade	All Activities
All Zones				
Activity Emp. Density	.058	.041	NA	.051
Vehicles/ Zone Acre	.846	.824	1.02	1.03
% Large Vehicles	NA	-.081	-.014	NA
Distance to CBD	NA	NA	.140	.117
Avg. Max. # Trips/Tour	.540	.426	.341	.698
Zone j Only				
Manufac. E.D.	.068	.129	.095	.125
Wholesale E.D.	.213	.333	.107	.205
Retail E.D.	.101	.172	.069	.077
Trucking E.D.	.021	.150	.076	.089
Railroad E.D.	NA	.013	NA	NA
Government E.D.	.021	.011	.012	.032
Other E.D.	.098	NA	.057	.077
Population D.	.509	NA	.234	.235
Distance to CBD	-.160	-.416	-.427	-.235
% Large Vehicle Trips	NA	NA	NA	-.078

(E.D.=Employment Density)

example, although wholesaling and trucking and warehousing employment have the highest coefficients in the manufacturing trip attration equation, the elasticities indicate that it is the linkages to population and wholesaling that account for the highest proportions of manufacturing trip attraction. The population-serving orientation of many goods vehicle trips discussed previously is further evidenced by the relative magnitude of the elasticities of trade and total activity trip attraction rates with respect to residential population/zone acre.

The elasticities with respect to wholesale employment/zone acre convey roughly the same impression as the model coefficients of the importance of this activity as an attractor of goods vehicle trips. The elasticities with respect to trucking and warehousing employment per zone acre, however, indicate that, although this activity is an intense trip attractor, changes in its level would yield lower percentage increases in the various categories of trips attracted than percentage increases in many sectors of socio-economic activity.

It may also be noted that the elasticities with respect to zonal location convey an even stronger sense of the decline in trip attraction rates with increasing distances from the center of the region. However, this effect is more likely attributable to long-run locational forces than an indication of potential short-run responses of any type.

6.3.5 Total Industry Zonal Trip Generation

Estimates of total zonal trip generation for manufacturing, for-hire transport, trade, and total activity were obtained by summing the corresponding tour frequency rate and trip attraction rate estimates. These estimates were then compared with the actual trip generation rates. The simple correlation coefficients between the estimated and actual trip generation rates were .93 for manufacturing, .91 for for-hire transport, .92 for trade, and .96 for total activity.

Regressions of observed versus predicted trip generation rates were also estimated; the results are shown in Table 6.3-11. The estimates indicate strong statistical relationships between the actual and predicted trip rates. None of the constant terms were found to be statistically significant, and the coefficients of the estimated trip rates were close to unity. The coefficients for the transport, trade, and total activity models are, however, statistically significantly different from zero at the 1% confidence level. Inspection of the residuals indicated that errors in the predictions of tour frequencies were the

TABLE 6.3-11

Results of Regressions of Observed Versus

Estimated Trip Generation Rates

Explanatory Variables	Observed Trips Generated/Zone Acre			
	Manufactur.	Transport	Trade	All Activities
Constant	-.03391 (-1.06)	-.01509 (-.60)	-.01173 (-.24)	.00312 (.03)
Estimated Trips Generated/ Zone Acre	1.01475 (64.10)	1.04844 (55.02)	.95619 (57.36)	.95372 (86.46)
$\bar{R}^2$	.87	.83	.84	.92
F	4108.5	3027.1	3291.0	7475.2

principal source of the errors in the trip generation predictions.

To obtain a measure of the accuracy of the estimates of total trip generation, the root mean square (rms) errors of the predicted and actual trip generation rates were calculated for the four activity groups. The ratios of these root mean square errors to the corresponding mean trip rates were 102% for manufacturing, 138% for for-hire transport, 84% for trade, and 65% for the combined, total activity model. The largest error ratios were associated with the smallest mean trip generation rates. This, of course, does not imply that a full set of "disaggregated" industry models would not outperform a total activity model in terms of rms error or some other evaluation criteria. Data limitations, however, precluded making this comparison within the research effort.

Although these error ratios may seem high, it is important to remember that models may be judged by many criteria, and that the choice of appropriate criteria depends on the purposes of model building. Although small rms errors would be desirable for a forecasting model, "a model designed to test a specific hypothesis or measure some elasticity should have high t-statistics." (Pindyck and Rubinfeld, 1976, p. 315). The industry goods vehicle trip generation models were designed for the latter purposes and fulfill the appropriate criteria quite acceptably.

Elasticities of the zonal industry trip generation rates with respect to their respective determinants were computed at their mean values, and these are shown in Table 6.3-12. The trip generation rate elasticities are equal to a weighted sum of the corresponding tour and trip attraction rate elasticities.[11] Since the mean trip attraction rates are very much larger in magnitude than the mean tour frequency rates and since many of the tour frequency and trip attraction elasticities are equal, there is close correspondence between the trip generation rate elasticities and the trip attraction elasticities.

The elasticities with respect to activity employment density, vehicle supply, the percentage of large vehicles, and distance to the CBD are the same as the tour frequency and trip attraction rate elasticities with respect to these same variables. The elasticities with respect to the average maximum number of deliveries per tour are positive but smaller than the corresponding trip attraction elasticities because of the contribution of the negative elasticities of tour frequency with respect to this

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[11]This is a rule for the elasticity of a sum of two functions (Manheim, 1977).

TABLE 6.3-12

Good Vehicle Trip Generation Rate Elasticities

Explanatory Variables	Manufactur.	Transport	Trade	All Activities
All Zones				
Activity Emp. Density	.058	.041	NA	.051
Vehicles/ Zone Acre	.846	.824	1.02	1.03
% Large Vehicles	NA	-.081	-.014	NA
Distance to CBD	NA	NA	.140	.117
Avg. Max. # Trips/Tour	.456	.366	.224	.601
Zone j Only				
Manufac. E.D.	.063	.121	.086	.114
Wholesale E.D.	.197	.313	.097	.186
Retail E.D.	.093	.162	.062	.070
Trucking E.D.	.019	.141	.069	.081
Railroad E.D.	NA	.012	NA	NA
Government E.D.	.019	.010	.011	.029
Other E.D.	.090	NA	.051	.070
Population E.D.	.470	NA	.211	.214
Distance to CBD	-.148	-.392	.386	-.214
% Large Vehicle Trips	NA	NA	NA	-.025

variable. Nevertheless, the net effect of increases in trip chaining will be substantial increases in goods vehicle trip generation.

The elasticities of goods vehicle trip generation rates in zone j with respect to changes in zone j variables are proportionately smaller than the corresponding trip attraction rate elasticities because, under the assumption made previously, changes in these variables do not affect the tour frequency rates; thus, the effect of a 1% increase in these quantities has a slightly smaller effect upon the trip generation rates than on the trip attraction rates. Because the trip generation elasticities are composites of the tour frequency and trip attraction rate elasticities, their appropriate interpretation is in terms of the component elasticities. Since these have been discussed at length, the previous discussion points will not be repeated.

6.4 Conclusion

For all its limitations, the empirical analysis has a number of important implications concerning the short-run relationship between the transport of goods and urban spatial structure. These include findings on the consequences of trip chaining, the range and magnitude of factors determining goods vehicle traffic, and several theoretical and methodological issues.

From a theoretical perspective, perhaps the most important finding obtained is the empirical evidence that a high degree of trip chaining is characteristic of goods vehicle traffic in urban areas and that trip chaining is also a significant determinant of levels of goods vehicle trip generation. The data tabulations in the first part of the chapter established that the majority of goods vehicles make only one tour a day, but serve a great many demands for goods collection and delivery. Measurements of the average degree of trip and delivery chaining for vehicles operated for manufacturing, local for-hire transport, and wholesale/retail trade revealed an average of more than 9 trips and deliveries per tour.

Results from the estimation of the trip generation model system indicated that the elasticities of zonal industry trip generation rates with respect to the average maximum number of trips per tour are in the range of .3 to .7. This suggests that changes in trip chaining would bring about quite considerable changes in the level of goods vehicle traffic in urban areas. Moreover, this finding points to constraints of vehicle capacity and transport pattern duration and other factors influencing trip chaining as important determinants of industry trip frequencies.

Another consequence of trip chaining is that most of the trips made by transport providers are made at locations which are remote from the activity which generates them. As a result, it is clearly insufficient to model trip or consignment frequency alone.

A finding which is also of some theoretical as well as practical significance is the apparent importance of higher-order decisions on vehicle supply (and implicitly on logistical arrangements) as determinants of the demand for goods vehicle trips. This conclusion points to the importance of future research concerning the empirical determinants of firms' vehicle supply.

Indirect evidence that firms' decisions about location and trade influence goods vehicle trip generation is also provided by the empirical results. Pronounced locational variation in trip attraction rates were found for all four industry groups. The evidence for locational variation in trip frequency rates was less clearcut and was only significant for wholesale and retail trade. It is, of course, quite possible that location by itself has no effect, but that other factors which are correlated with location are determinants of trip generation. Measurements of trading patterns and the distributions of consignment sizes would be most instructive in further exploration of this question.

An obvious weakness of the analysis is its highly aggregate character involving aggregation over firms, commodities, and industries. Slight compensation for this deficiency may be provided by the fact that it permits some overall statement to be made about the most important attractors of urban goods vehicle traffic. In this regard, the empirical results indicate that trucking and warehousing employment and wholesaling employment have far and away the highest trip attraction rates per employee. This may suggest that strategies to facilitate the movement of goods within urban areas might begin with these activities.

The modelling approach employed in the empirical analysis proved to be workable and appeared to give reasonable results. From a methodological point of view, its principal advantage, apart from feasibility, was that the multi-equation approach permitted a deeper investigation of trip generation than could have been performed with a single equation model. As a result, it was possible to separate out some of the differential and offsetting effects of the causal variables on the constituent components of total trip generation.

Probably the most serious deficiency of the modelling approach is in how many important aspects of goods transport demand were left exogenous and not determined within the modelling framework. For example, explicit treatment of goods purchases and sales, consignment sizes, vehicle supply, trip chaining, and trip distribution would seem warranted. Apart from better data, further advances in freight transport theory and modelling methodology will be required to make these improvements. Clearly, considerable research will be necessary in order to develop accurate and reliable policy-sensitive models for urban freight transport planning.

Chapter 7 An Empirical Analysis of Goods Vehicle Trip Distribution

This chapter presents the results of an exploratory analysis of the spatial arrangement of trips in complex goods vehicle transport patterns. The purpose of this analysis was to provide a pilot test of the hypotheses concerning trip distribution probabilities developed as part of the paradigm of trip chaining behavior proposed in Chapter 3. The first hypothesis introduced there was that vehicle routing and scheduling behavior leads to "gravity like" disaggregate trip distribution patterns in which the probability that a trip is made between two nodes is a function of their spatial separation. It was suggested, however, that this explanation of trip distribution was only a crude first approximation. The major implication of the paradigm was the more general hypothesis that, in addition to internodal distance, other spatial attributes of alternative trip destinations and constraints on tour and transport pattern duration were also likely to be determinants of trip origin-destination patterns. Investigation of this more comprehensive hypothesis was the major objective of the empirical analysis.

The organization of this chapter is as follows. In section 7.1, the modelling approach and the data used in the empirical analysis are described. The analytical approach entails the formulation of a multinomial logit model of trip destination probabilities. In section 7.2, hypotheses regarding the determinants of these probabilities are discussed in terms of alternative model specifications. The results of estimation of the models are presented and interpreted in section 7.3. Lastly, major conclusions are summarized.

7.1 The Modelling Approach

As defined previously, the firm's trip distribution problem involves the determination of the spatial arrangement of goods vehicle trips within its daily transport pattern. For the purposes of analysis, it is assumed that these decisions are made in a context in which the vehicle tour frequency and trip attraction by location are predetermined and given. Therefore, the trip linking problem is reduced to the choice of a trip destination (or origin) from the set of feasible alternatives for each trip origin (or destination).

In order to make the problem of assessing the determinants of spatial patterns of goods vehicle trips tractable, we further assume that the decisions to connect each pair of the nodes within the firm's transport patterns are independent of decisions linking all other nodes.[1] This permits us to formulate the trip linking or destination choice problem as the choice of a destination from a set of mutually exclusive alternatives conditional upon the origin of each trip.

In order to operationalize an empirical test of hypotheses concerning the determinants of spatial patterns of goods vehicle trips, a multivariate statistical model is utilized to explain the choices among the discrete alternatives for each trip link. The model selected for the empirical analysis and the reasons for its selection will be discussed next.

7.1.1 The Multinomial Logit Model

Within the framework of multivariate analysis, there are a variety of statistical models that might be proposed for the explanation of qualitative, polychotomous dependent variables. One that has proven advantageous is the multinomial logit model which has been extensively used in the analysis of urban travel demand.[2] The multinomial logit (MNL) model relates the probability, P_{jt}, that observation t

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[1]This is the same simplification of reality adopted in the paradigm of firm behavior in Chapter 3.
[2]Excellent overviews of disaggregate travel demand modelling and the application of the multinomial logit model are given by Ben Akiva (1977) and McFadden (1977b).

takes response j from a set of mutually exclusive alternatives, A_t, to a function U_{jt} of the attributes of the alternative j and the attributes of the observation according to the functional form shown in equation 7.1.

$$P_{jt} = \frac{e^{U_{jt}}}{\sum_{q \varepsilon A_t} e^{U_{qt}}} \tag{7.1}$$

The model takes its name from the fact that the functional form for the probabilities is the standardized multivariate logistic cumulative distribution. For computational reasons, U_{jt}, commonly referred to as the utility function, is taken to be linear in the parameters α_j and β_j and may be written as a function of an array of attributes of the alternatives, X_{jt}, and an array of attributes of the observations, Z_t, plus a random unobserved error component, ϵ_{jt}.

$$U_{jt} = \alpha_j X \quad + \beta_j Z_t + \epsilon_{jt} \tag{7.2}$$

where α_j and β_j are arrays of coefficients to be estimated. An assumption of the MNL model is that the ε_{jt} are independently and identically distributed Weibull variates (Talvitie, 1976).

Estimates of the coefficients are typically obtained by the method of maximum likelihood since there are limitations to the utilization of ordinary least squares. The maximum likelihood estimates have been shown to be asymptotically efficient and asymptotically normally distributed (McFadden, 1974, p. 119) and thus provide the basis for the construction of tests of hypotheses concerning the model parameters.

The multinomial logit model was selected for use as an empirical model of disaggregate goods vehicle trip distribution for several reasons. The most important among these reasons were its desirable statistical properties and computational considerations of feasibility and cost for the size of the problem application envisioned. Additionally, McFadden (1974) provides theoretical motivation for multinomial logit as a model of individual choice behavior.

A possible deficiency of the multinomial logit model for application to a destination choice problem is the assumption needed to obtain unbiased estimates of the parameters that the unobserved error components of the utility function are independent.[3] Violations of this assumption will occur if destinations which are similar in their observed attributes are also similar in their unobserved attributes. They may also occur in this

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[3]This frequently is referred to as the assumption of the independence of irrelevant alternatives.

modelling context because there may be systematic effects not captured in the utility functions because of the fact that decisions about different trip links are not independent. Indeed, the theoretical motivation for this empirical analysis of goods vehicle trip patterns was the hypothesis that variables other than internodal distances might influence trip linking probabilities. If these effects can be identified and incorporated in the systematic component of the utility functions, then the problem will be reduced. In the event we cannot identify or measure these systematic effects, it is possible that their impact on the parameter estimates will be small. Considerable evidence suggests that the multinomial logit model is robust with respect to violations of these assumptions (McFadden et al., 1977).

A problem encountered in modelling destination choice and in other contexts is that we typically only have information on chosen grouped alternatives such as destination zones rather than on the actual destination locations chosen within those zones. Often, in destination choice problems, we also lack information concerning the characteristics of the alternatives within groups and have only information on the characteristics of the grouped alternatives to work with.

Lerman (1975) has shown that if the multinomial logit model applies to the ungrouped or "elemental" alternatives then the probability of a group of alternatives, J, can be approximated by

$$P_{Jt} = \frac{e^{\overline{U}_{Jt} + \ln N_{Jt}}}{\sum_{Q_t \varepsilon A'_t} e^{\overline{U}_{Qt} + \ln N_{Qt}}} \tag{7.3}$$

where $\overline{U}_{Jt}$ and $\overline{U}_{Qt}$ are the mean utilities of grouped alternatives J_t and Q_t for observation t (with grouped choice set A'_t) and N_{Jt} and N_{Qt} are the number of elemental alternatives in J_t and Q_t, respectively. "This approximation is exact when all the alternatives are identical in their measured attributes.... Furthermore, Lerman has shown that at least in a simple case this approximation is relatively robust; fairly large variations within a group produce relatively small errors in the approximation." (Lerman and Adler, 1976, p. 136).

In the case of the trip linking problem, this approximation makes it possible for us to model trip links between zones rather than nodes, reducing the number of alternatives for each trip origin to a manageable size. By grouping alternative destinations within destination zones, we also do not need information, which is lacking, on the attributes of each chosen alternative; we simply need to specify the attributes of the grouped alternative which can be obtained from available data.

The $\ln N_{Jt}$ term appears in equation 7.3 without a coefficient (i.e., with a coefficient constrained to unity). This is necessary for the estimates of the mean utility function parameters to be independent of the grouping or zoning system employed. Although we cannot tell a priori that the assumptions of the grouped logit model will hold, one test of this hypothesis is provided by obtaining the maximum likelihood estimate for the log group size coefficient along with the others. A log group size coefficient estimate significantly different from 1 indicates the violation of the model assumption that the errors are uncorrelated across the alternatives. This may reflect a violation of the assumption that multinomial logit applies to the choice among elemental alternatives, a lack of similarity among the alternatives within the grouped alternatives, or equally serious and possibly related, econometric problems such as other specification or measurement errors. Therefore, estimating models with both unconstrained and constrained log group size coefficients is an important diagnostic.

To implement the grouped MNL model a measure of the size of each group, N_{Jt}, for observation t is needed.

Within the conditional choice framework for the trip linking analysis, an exact and natural measure of group size is the number of trip links terminating in each zone and at the depot. Note, however, as was discussed in section 3.3, the precise number of alternatives within each group depends on the trip origin. For example, for trips originating at the depot, the depot is not a feasible destination. Moreover, since a node cannot be linked to itself, the number of elemental alternatives for intrazonal trips must be reduced by 1. Only if the number of trip destinations is large could we assume that this restriction is unimportant. For disaggregate models of trip linking this will seldom be the case, and equation 3.36 should be used as the correct measure of N_{Jt}.

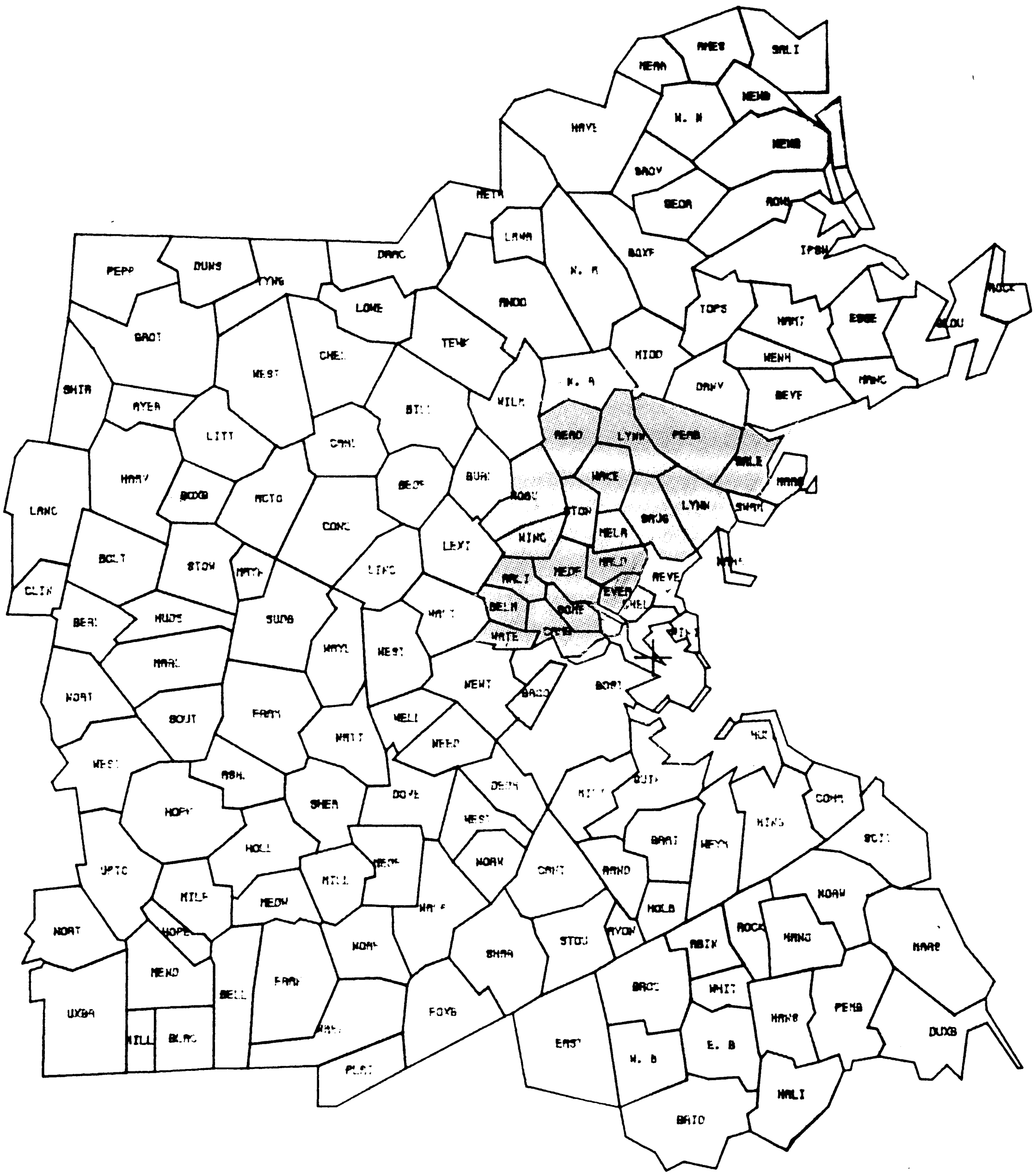
Alternative hypotheses concerning the determinants of trip link probabilities can be tested by incorporating them in the mean utility function. Estimation of the model will yield estimates of the size and significance of the different causal variables as determinants of trip destination choice.

7.1.2 The Data

The data used to estimate the goods vehicle trip destination choice models was a subsample drawn from the survey data of the trips made by goods vehicles operated by food manufacturers within the 19 town area indicated in Figure 7.1-1. Because, as explained previously, disaggregate data on firms' transport patterns were not available, data on the trip patterns for individual vehicles were utilized in the empirical analysis instead. In the case of the routing choices made by multi-vehicle operators, this corresponds to sampling a subset of choices. This would not be a problem except for the fact that it means we will infer smaller choice sets for the observed trip origins than may actually be available. Fortunately, McFadden *et al.* (1977, p. 57) "has shown that consistent statistical estimates of the utility function can be obtained using fixed or random subsets of all available alternatives". In the case of single vehicle fleets, there is obviously no disparity between the goods vehicle trip pattern and the firm's daily transport pattern. Evidence given previously (U.S. Census of Transportation, 1963) indicates that a majority of vehicles in local operation are in fleets of one vehicle.

A variety of considerations influenced the choice of the sample data for the empirical analysis. Theoretical considerations indicated the advisability of limiting the trip records to those pertaining to vehicles operated by providers in the same activity classification and in similar

Figure 7.1-1 The Subsample Area



locations within the region. These criteria were thought to be important in obtaining a sample that would correspond to a set of behavioral units with some similarity, or at least less variability, in the unobserved factors that might influence their transport operations, including their location, market areas, and commodities produced.

Another consideration was that the multinomial logit model package available for use was limited to formulations of 20 or fewer alternatives (National Bureau of Economic Research, 1976). Because of the great disparity in trading/consignment patterns at the micro level, it was thought to be difficult to find a large enough sample of observations for which there would be no more than 20 alternatives in common. Moreover, there was a concern that searching the full set of survey records for those that would conform to this restriction might invalidate the results or confound their interpretation. The use of larger groupings than traffic zones was one way to overcome this problem and had the added advantage that trips were not restricted to a very small geographic area. Obviously the possibility of misleading parameter estimates would arise if long trips were systematically excluded from the sample.

Another factor was the choice of an activity which was fairly common within the region so that more observations would be available. Wholesaling and retail sub-activities were considered but rejected. Wholesaling activities were not sufficiently subdivided in the industrial classification to allow a group of similar activities to be identified. Retail activities were finely classified, but it was thought that their vehicle trip patterns might be atypical because of their population-serving orientation. Consequently, a manufacturing industry active in the local market as a producer and transport provider was sought. Food manufacturing was selected because it seemed to meet these criteria.

One reason for the choice to sample from the 19 town area to the north of Boston proper was the somewhat higher incidence of food manufacturing activity and trip-making there than elsewhere in the region. A grouping of contiguous towns with convex boundaries was also desirable to minimize the need to exclude observations because of trips crossing the subsample area boundaries. Other desirable characteristics were the absence of extreme variation in the densities of activities and a reasonably uniform internal road network. The former of these characteristics might lead to considerable unobserved variation in the alternatives within the destination towns. An highly non-uniform section of the road network could cause problems in utilizing average network travel times as the measure of distance in the model. Judged against all these criteria, the indicated area seemed the best choice.

Examination of all the vehicles based within the area yielded a sample of 18 vehicles whose trip patterns were wholely contained within the area.[4] These vehicles made a total of 396 trips; this was felt to be a more than sufficient number of observations to obtain reliable coefficient estimates.[5] The fact that only 18 vehicle trip patterns were in the sample was not considered a liability. In theory, the hypothesized effects should be present in individual transport patterns as well as in a cross-section. However, because of the fact that the sample data pertain to just one activity in one location, no claim is made that the findings provide conclusive evidence regarding the hypotheses tested. Rather, it is suggested that these results be considered as a preliminary pilot test which may warrant and guide subsequent empirical investigation.

All of the trip destinations were within 13 of the 19 towns in the area that was sampled. Thus the maximum number of alternative destinations for each trip origin was 13 plus one for its base. Because of the interest in testing

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[4]The area is sufficiently large relative to the length of goods vehicle trips that long trips were not excluded.
[5]Unfactored trip records were utilized for the empirical analysis.

hypotheses concerning the determinants of trip links to the depot, the depot was considered a separate alternative in the models.

The coding of the feasible alternatives for each observation employed the restriction that only trip destinations reached on tours from the same depot were feasible alternatives for trips made by that vehicle. Also imposed was the restriction that a trip could not terminate at its own origin. Thus if there were only one trip origin in a given town for a vehicle, the origin zone could not be a feasible destination choice for that observation.

Obviously these procedures greatly reduced the number of alternatives for most of the observations. In fact, in contrast to gravity trip distribution models in which all alternatives are typically assumed feasible, there averaged approximately 3-4 different alternatives for each observation including the depot.

Of the 396 trips, 30% were made by 2-axle-6-tire vehicles and 70% by smaller 2-axle-4-tire vehicles. All of the vehicles were privately licensed. The distribution of trip purposes was 54% retail deliveries, 40% wholesale deliveries, and 6% returns to the depots.

An important characteristic of the data was that 88% of all the trips were intratown trips. Although this percentage may seem high, it was not thought to be unrepresentative. Regionwide, approximately 70% of all trips made by all activities were intratown trips. A higher incidence of shorter trip links would be expected in relatively central locations where market areas are of smaller spatial extent.

The high percentage of intratown trips raised two concerns about the empirical analysis. The first was that the use of towns instead of smaller destination alternatives might mask some of the spatial effects hypothesized. A potential mitigating factor was that more than 57% of the intratown trips were made in towns other than those in which the vehicles were based. Nevertheless, it was recognized that the empirical test might yield inconclusive results in the form of large standard errors for the coefficient estimates; fortunately, this did not prove to be the case.

A second concern was that poor measurement of intratown travel times might affect the size of the coefficient estimates. To reduce this possibility, estimates of the mean intratown travel times were calculated by taking the mean of the lengths of the interzonal and intrazonal trips made within each town. Nothing could be done about improving the accuracy of the intrazonal travel times without better data. Given the hypothesis that vehicle routing and scheduling decisions result in distance minimizing behavior, it is possible that intrazonal travel times overestimate the actual length of the intrazonal goods vehicle trips. This may mean than trip destination choices are even more sensitive to the hypothesized effects than implied by the model coefficients.

7.2 Disaggregate Trip Distribution Hypotheses and Model Specifications

The paradigm of behavior discussed in Chapter 3 suggested a variety of hypotheses concerning disaggregate trip distribution probabilities. These hypotheses provide the basis for the alternative specifications of the utility functions that were estimated empirically.

The simplest specification consistent with the paradigm is

$$U_{Jt} = \alpha_1 TTIJ_t \qquad (7.4)$$

where $TTIJ_t$ is the travel time from origin town I for observation t to alternative destination town J, and α_1 is a parameter to be estimated. Note that $TTIJ_t$ varies with both the observation t and the alternative J. The grouped multinomial logit model with this utility function is a disaggregate version of the singly constrained gravity model.

$TTIJ_t$ does not include the average terminal time or the average time needed for parking the vehicles. As a first approximation, these should not affect the sequence in which deliveries are made unless there is substantial variation by time of day. Since the estimates of terminal times available from the travel survey were auto-based measures averaged over all off-peak trips, it seemed undesirable to leave them in the travel time measurements; therefore they were deleted. If accurate measurements of the variation in parking and delivery times by location and by time of day can be obtained in future data collection efforts, it will be possible to make an empirical test of their effects, if any, on trip linking.

Equation 7.4 embodies the hypothesis that the only systematic effect on trip link destination probabilities is that of travel time from the trip origin to the alternative destinations. Moreover, this effect is generic, not alternative-specific (i.e., it does not vary with the destination alternatives). All other determinants of the probabilities are implicitly assumed to be random in their effects.

Another one parameter specification for the utility function suggested by the behavioral paradigm is the savings function, $SAVIJ_t$, shown in equation 7.5

$$U_{Jt} = \alpha_1 \; SAVIJ_t$$

$$= \alpha_1 \; (TTDI_t + TTJD_t - TTIJ_t) \qquad (7.5)$$

where $TTDI_t$ is the travel time from the depot to the trip origin I for observation t, $TTJD_t$ is the travel time from the destination alternative J to the depot, and $TTIJ_t$ is as defined above.

When J is the depot, the savings function is zero in magnitude. As a result, it was recognized that the savings function may tend to underrepresent the attractiveness of the depot as an alternative.

A better specification which was designed to capture the systematic effects of spatial interdependence and also allows for a different utility function for the depot alternative, D, is equation 7.6.

$$U_{Jt} = \begin{cases} \alpha_1 (TTDI_t + TTJD_t) + \alpha_2 TTIJ_t, \forall J \neq D \\ \alpha_3 CONDEP + \alpha_4 TTID_t, J = D \end{cases} \qquad (7.6)$$

In equation 7.6 the utility of a non-depot alternative J is given by a modified savings function of the sum of the travel time from the depot to the origin, $TTDI_t$, and the travel time from J to the depot, $TTJD_t$, and a second term, the travel time to J from the trip origin, $TTIJ_t$. The probability that J will be the trip destination for observation t is hypothesized to increase with ($TTJD_t$ + $TTDI_t$) because of increased travel time savings (holding $TTIJ_t$ constant) and to be inversely related to $TTIJ_t$. Therefore, we would hypothesize a positive sign for α_1 and a negative sign for α_2. As discussed in Chapter 3, the relative size of α_1 and α_2 may depend on firm behavior. Alternatively, their relative magnitude may be problem dependent.

An important feature of equation 7.6 is that it has a separate utility function for the depot alternative. The reason is that distance is hypothesized to have a different effect on the probability that the depot is chosen as a trip destination than it has on the choice of other alternatives.[6] In particular α_3 is expected to be smaller than α_2 because factors other than travel time may require returns to the depot. The most likely causes are the

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[6]TTDJ does not appear in the utility function for the depot alternative because it is zero for this trip destination choice. TTDI is not in the utility function because it is equal to TTID.

constraints on tour and transport pattern duration which are omitted from the model because of data limitations.

Because of omitted variables, it is quite possible that there will remain systematic differences among the alternatives after accounting for the effects in the model. To test this hypothesis and because they are needed for unbiased parameter estimation if this hypothesis cannot be rejected, alternative specific constants are required. However, since the non-depot alternatives vary over the observations, separate alternative-specific constants for each of the non-depot alternatives would be inappropriate. Therefore, an alternative-specific constant is utilized only to account for systematic effects influencing the choice of depot versus non-depot alternatives. The choice of which of these has the alternative specific constant is arbitrary[7] and the constant, CONDEP, has been placed in the depot utility function in (7.6). The specification of the utility function as shown in (7.6) most closely represents the hypotheses which follow from the paradigm of the firm's vehicle routing and scheduling behavior. Consequently this model was strictly preferred on a priori grounds over other alternative models feasible with the available data.

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[7]It will attain the same value in either, but with an opposite sign.

7.3 Trip Distribution Model Results

A variety of different multinomial logit trip distribution models were estimated. First, the simple one parameter models using generic travel time and savings function utility functions were estimated. This was done to get some feeling for the feasibility of the approach and to provide a basis of comparison for the more comprehensive model.

Next, the full comprehensive model was estimated. Although the model fits the data well, the coefficient of one variable was not significantly different from zero. As a result, the model was reestimated with the insignificant variable excluded to obtain final coefficient estimates.

Both unconstrained and constrained versions of each of the models were estimated. In the unconstrained version, the maximum likelihood value of the coefficient of the log of the groupsize variable was estimated. In the constrained version, this value of the coefficient was constrained to unity.

For each set of model estimates, various statistics are reported. Asymptotic t-statistics are given (in lieu of standard errors from which they are computed) for each coefficient estimate. These are used in tests of significance of individual parameters. The values of the log likelihood function when all the parameters are zero, $L^*(0)$, and at the estimated coefficients, $L^*(\alpha)$, are used in likelihood ratio tests of hypotheses about groups of parameters and in assessing goodness of fit. The likelihood ratio index, $\rho^2 = [1-L^*(\alpha)/L^*(0)]$, is a test statistic somewhat analogous to R^2 for ordinary least squares models. Although ρ^2 may take values from 0 to 1, it is not directly comparable to R^2; typically "values of .2 to .4 for represent an excellent fit" for disaggregate data (McFadden _et_ _al_., 1977, p. 35).

Another measure of goodness of fit is the percentage of the observations correctly predicted, where the predictions are the alternatives with the largest probabilities for each observation. Since the number of observations (396) is the same for all the disaggregate models to be discussed, we simply report the number of correct predictions.

The results for the trip distribution model with the one parameter travel time and savings utility functions are shown in Table 7.3-1. All of the coefficients in both models have the expected sign and are statistically significant. Both models fit the data quite well in terms of ρ^2 and the number of correct predictions. This was not

TABLE 7.3-1

Results of the One Parameter "Travel Time" and "Savings" Logit Models

The Travel Time Model

Explanatory Variables	Unconstrained Estimates		Constrained Estimates	
	Coefficient	t-statistic	Coefficient	t-statistic
TTIJ	-.2109	-6.82	-.2024	-6.36
$LN(N_J)$	.7423	8.67	1	NA
$L^*(0)$	-348.263		-348.263	
$L^*(\hat{\alpha})$	-120.917		-124.737	
ρ^2	.65		.64	
# correct	356		354	

The Savings Model

Explanatory Variables	Unconstrained Estimates		Constrained Estimates	
	Coefficient	t-statistic	Coefficient	t-statistic
SAVIJ	.1232	5.27	.1156	4.78
$LN(N_J)$	.7850	9.45	1	NA
$L^*(0)$	-348.263		-348.263	
$L^*(\hat{\alpha})$	-134.672		-137.535	
ρ^2	.61		.61	
# correct	350		344	

unexpected; because of the high incidence of intratown trips (348), the travel time model was expected to predict a large number of the observations correctly. This, however, should not be taken to lessen the value of the results. The high incidence of very short trips is one of the principal consequences of vehicle routing and scheduling behavior.

In both models although the coefficients of ln N_J are not far from 1; however, they are significantly different from 1 at the 1% confidence level. The estimated coefficients for the constrained models are very similar to those from the unconstrained models. As would be expected, the summary statistics for the constrained models are not as good as for the unconstrained models which have an extra degree of freedom.

The results for the travel time model support the hypothesis that the proximity of alternative destinations is an important factor influencing the trip links formed in vehicle routing and scheduling decisions. This suggests that with proper representations of feasible alternatives, gravity-type models provide at least a first approximation to goods vehicle trip distribution.

The results for the one parameter savings model are not quite as good as those for the travel time model. This is evidenced by the somewhat lower values for ρ^2 and the number of correct predictions. Consequently, the savings model provided no clear indication that factors other than proximity influence trip link probabilities. No conclusive explanation was readily at hand for the slightly poorer fit of the savings model. One possibility considered was that the travel time model had a better specification than the savings function for both the depot and non-depot alternatives. Support for this idea as well as a more conclusive test of the presence of more complex spatial interdependence in the arrangement of trip links in goods vehicle transport patterns was provided by the multi-parameter models.

The results for the full specification of the trip distribution model (with the utility function of equation 7.6) are shown in Table 7.3-2. All of the coefficients in the unconstrained model have the correct sign. The model fits the data well and has an higher ρ^2 and number of correct predictions than the previous models. The coefficient of ln N_J is significantly different from 1. As discussed before, this may reflect some degree of sampling error, specification error, some failure of the independence assumptions of the grouped multinomial logit model, or a combination of these factors. This suggests the need for some caution in drawing inferences from the model. On the

TABLE 7.3-2

The Full Specification of the Disaggregate

Trip Distribution Model

Explanatory Variables	Unconstrained Estimates Coefficient	Unconstrained Estimates t-statistic	Constrained Estimates Coefficient	Constrained Estimates t-statistic
(TTDI + TTJD)	.0575	1.35	.0799	1.78
TTIJ	-.2541	-7.08	-.2459	-6.68
TTID	-.0190	-.29	.0047	.07
CONDEP	-1.6848	-2.44	-.5987	-1.05
$LN(N_J)$	.5985	4.03	1	NA
$L^*(0)$	-348.263		-348.263	
$L^*(\hat{\alpha})$	-116.077		-119.516	
ρ^2	.67		.66	
# correct	362		360	

other hand, a serious violation of the model assumption would be likely to have had much more drastic effects on the coefficient of $\ln(N_J)$. Arguably, the unconstrained estimates are less biased than the constrained estimates, and therefore we will concentrate on the results from the unconstrained model.

The coefficient of (TTDI + TTJD) has the expected positive sign and is significant at the 90% confidence level for the unconstrained model. Consistent with the savings function concept, the probability that an origin will be connected to a non-depot destination will vary with the location of the origin and the destination and increase as a function of the sum of their travel times from the depot, holding all other factors constant. This constitutes important evidence for the hypothesis that spatial attributes of vehicle routing and scheduling problems other than proximity to the trip origin are determinants of trip link probabilities.

The coefficient of origin to destination travel time for the non-depot alternatives, TTIJ is significant at the 1% level and is somewhat larger in absolute value than in the single travel time model. In contrast, the coefficient of travel time from the trip origin for the depot alternative is considerably smaller in absolute value as hypothesized. Moreover, it is not significantly different from zero.

A likelihood ratio test of the hypothesis that the effect of travel time on trip destination probabilities is the same for both depot and non-depot alternatives was performed by reestimating the unconstrained model with a generic travel time variable. The value of the log likelihood function at the maximum likelihood estimates of the parameters of the model with this (one) restriction was -120.046. McFadden (1974) has shown that the statistic $-2[L^*(\hat{\alpha}^H) - L^*(\alpha)]$ is distributed approximately as chi-square with H degrees of freedom, where H is the number of restrictions embodied in the restricted (null) hypothesis. The value of the statistic was 7.938 which is greater than the critical value of the chi-square distribution with one degree of freedom at the 1% confidence level. Therefore, we can reject the hypothesis that the origin to destination travel time has the same effect on the choice between the depot and the non-depot alternatives.

In view of the small magnitude and insignificant coefficient of TTID, it appears that the travel time to the depot does not influence its selection as a trip destination. Rather, it would seem that factors omitted from the model such as constraints on vehicle capacity are the principal determinants of this choice. This is consistent with the significance of the constant for the depot alternative.

At this juncture, a final disaggregate trip distribution model was reestimated with TTID omitted from the depot-alternative utility function. This model is shown in Table 7.3-3. As indicated by inspection of the summary statistics, this model is very similar to the full specification in terms of goodness of fit. There is also very little change in the parameter estimates. However, the estimated coefficient of (TTDI + TTJD) has a smaller standard error and hence a higher t-statistic.

It may be recognized that the model in Table 7.3-3 is a restriction of the simple one parameter "travel time" model introduced previously. The application of the appropriate likelihood ratio test allows us to test the null hypothesis that the additional variables have no effect on trip linking probabilities. For this comparison, the test statistic has the value 9.6 which is greater than the critical value of chi-square with 2 degrees of freedom at the 1% confidence level. Therefore, we reject the null hypothesis that factors other than proximity have no effect on goods vehicle origin-destination patterns.

TABLE 7.3-3

Coefficient Estimates for the Revised

Disaggregate Model

Explanatory Variables	Unconstrained Estimates		Constrained Estimates	
	Coefficient	t-statistic	Coefficient	t-statistic
(TTDI + TTJD)	.0650	1.93	.0782	2.11
TTIJ	-.2556	-7.16	-.2456	-6.73
CONDEP	-1.7675	-2.82	-.5733	-1.32
$LN(N_J)$	.6049	4.12	1	NA
$L^*(0)$	-348.263		-348.263	
$L^*(\hat{\alpha})$	-116.118		-119.519	
ρ^2	.67		.66	
# correct	362		360	

Although the findings from the model suggest that the "savings" are a factor in the formation of trip links, it also seems that the relative size of the effect is small. The marginal rate of substitution between (TTDI+TTJD) and TTIJ is $[\partial U/\partial (TTDI+TTJD)]/[\partial U/\partial TTIJ]$ which is approximately -4 minutes per minute. This suggests that dispatchers would be indifferent between a one minute reduction in origin to destination travel time and a four minute increase in (TTDI+TTJD) and thus, in the savings, holding TTIJ constant. Consequently, the model results imply that considerably more weight is given to proximity than savings in forming trip links in transport patterns. However, in view of the high degree of spatial aggregation, the potential bias arising from the violation of the independence assumptions, and the fact that this ratio may be problem dependent, it is not suggested that the relative magnitudes of these coefficients will necessarily be transferable to other contexts.

7.4 Conclusion

The findings of the trip distribution analysis provide intuitively appealing statistical evidence of the effects of trip chaining on spatial patterns of goods vehicle traffic in urban areas. Although the findings are considered to be tentative because of the limitations of the analysis, there is considerable support for the theoretical arguments that many factors directly or indirectly influence trip destination probabilities. As a result, these findings also suggest that gravity models are misspecified in a number of important respects and may produce biased forecasts. For this reason, a concerted effort is warranted to collect and analyze data on firms' transport pattern decisions. With better data, especially on consignment sizes, vehicle capacities, labor work rules, and delivery deadlines it should be possible to test more elaborate hypotheses regarding the determinants of goods trip vehicle trip patterns.

Chapter 8 Conclusion

A number of overall conclusions emerge from the theoretical and empirical analysis conducted in this study. This chapter relates these findings and their limitations to recommendations for further research.

Urban Freight Transport Behavior

A major premise of this study was that the investigation of the behavior of urban freight transport providers would contribute to a deeper understanding of the determinants of goods vehicle traffic and its relationship to the spatial structure of urban areas. To this end, a theory of urban freight transport decisionmaking was proposed and used to structure the empirical analyses of goods vehicle trip generation and distribution. When judged in its entirety, the empirical work carried out appeared to be consistent with and supportive of the disaggregate theory of firms' transport pattern choices that was presented. However, because of the limitations of aggregate analysis, data availability, and the simplifying assumptions of the theory and the empirical models, it is thought that disaggregate empirical analysis of firms' transport pattern decisions is indicated to substantiate and extend the findings obtained.

Disaggregate analysis will require the collection of appropriate data on the operations of establishments' vehicle fleets. At a minimum, information is needed on logistical arrangements, transport facilities, vehicle fleet characteristics, consignments transported and their attributes, and the details of transport pattern choices including relevant constraints. Ideally, data would also be collected on the orders for goods which could be filled, the level of service provided, and other factors which may be pertinent to an empirical investigation of the choice of the consignments included in transport patterns. Finally, information on management perspectives and other qualitative factors bearing upon urban freight transport operations would also be desirable.

The motivation for disaggregate analysis of consignment frequency and goods vehicle trip generation is not limited to the desire to obtain more valid hypothesis tests or improved parameter estimates. Rather, considerably improved model formulation and specification and the ability to test new and deeper hypotheses are also expected.

The Determinants of Goods Vehicle Traffic

Comparison of the results obtained in the empirical analyses with the findings of other studies discussed in the literature review makes it clear that analyzing the determinants of goods vehicle traffic from the perspective of the providers of transport leads to different substantive conclusions than have been reached from other modelling perspectives. A variety of factors omitted from prior studies were found to have effects of considerable magnitude on goods vehicle traffic.

In accord with a major theme of this study, trip chaining was found to be characteristic of urban freight transport and an important determinant of trip generation and distribution. Theory suggested that the degree of trip chaining was determined by the interaction of transport pattern problem characteristics and relevant constraints. Therefore, the empirical findings may be interpreted as evidence that constraints of vehicle capacity and transport pattern duration are also significant determinants of goods vehicle traffic levels. As a result, policies which affect these constraints are expected to impact consignment frequency, trip generation, and trip distribution. This finding also provides at least indirect evidence that transport system characteristics affect goods vehicle traffic. For example, an improvement in network travel times is likely to relax a constraint on transport pattern duration if it is binding and may lead to an increase in consignment frequency.

A limitation of the analysis was that the degree of trip chaining was taken as given, rather than explained endogenously in the model system. In order to understand the consequences of changes in the characteristics of transport pattern decisions and their determinants, it would be desirable to model trip chaining directly. Therefore, the construction of explanatory statistical models of trip chaining should be undertaken in future research.

Another major conclusion was that some of the most important determinants of goods vehicle traffic are the result of longer-term decisions firms make about vehicle supply and distribution logistics. This finding points to the need to broaden the scope of inquiry to include these aspects of transport provider behavior. In particular, an attempt should be made to construct exploratory disaggregate behavioral models of firms' decisions on vehicle supply and characteristics. Because these decisions are interdependent with decisions concerning logistical arrangements, joint models may be required. Also, to understand logistical arrangements, it may also be necessary to consider the behavior of decisionmakers other than freight transport providers such as goods consumers.

The empirical analyses indicated the presence of locational variation in goods vehicle trip generation rates and raised unanswered questions concerning the effects of activity levels, location, and accessibility as determinants of goods vehicle traffic. In addition to issues concerning the relationship of goods transport to volumes of goods flows, these questions involve issues concerning intraurban and interurban trade and their relationship to other measures of the activity system such as employment. Because of the absence of data on volumes of goods purchases and sales and freight flows, it was not possible to investigate these issues in the empirical work. This should be feasible with a rather detailed level of data collection in future studies. However, because of the heterogeneity of production, consumption, trade, and transport at the level of individual establishments, it may prove difficult to isolate specific and transferable conclusions.

As reflected in its objectives, this study has focused greater attention on the relationship between goods vehicle traffic and flows of freight than on the relationship between trade flows and urban spatial structure. The former relationship also has implications for the analysis of the latter. In particular, trip chaining was found to bring about a reduction in transport costs and to reduce the rate at which transport costs increase as a function of the length of haul between shippers and receivers. This may lessen the importance of transport costs as a determinant of spatial patterns of intraregional trade.

The theoretical and empirical analyses evidence the fact that trip chaining considerably complicates the relationship between the transport of goods and urban spatial structure. Because goods consignments are transported in multi-destination tours, there is no simple relationship between patterns of intraurban trade and flows of goods vehicles. However, decisions about trade flows are critical determinants of the alternatives and the choices governing goods consignments and vehicle trips. Hopefully, this clarifies the role and heightens the importance of research on urban commodity flows in support of freight traffic planning and analysis while making it clear that, by itself, knowledge of goods purchases and sales does not make it a simple matter to ascertain transport flows.

Models of Goods Vehicle Traffic

The findings obtained in this study underscore the insufficiency of the models currently used to forecast goods vehicle traffic in urban areas. In view of the many complex theoretical and empirical issues involved, considerable research on intraurban trade and urban freight transport may be required to provide an adequate basis for the reformulation of planning models.

Apart from better theory and matching data, improved modeling approaches are also needed to further our understanding of the relationships linking the transport of goods to the activity system and to make useful planning models a reality. When judged against the proposed theory of urban freight transport behavior, a principal deficiency of the empirical models developed in this study was in the assumption of independence of the dimensions of transport pattern choices and the consignments and trips within them. Consequently, the development of models which take account of these interdependencies is an obvious direction for future research. In view of its importance, a major objective in this regard should be the development of improved procedures for modelling trip chaining.

In designing improved models of goods vehicle traffic, the importance of developing an integrated model system treating both trade and transport flows should also not be overlooked. Satisfactory integrated models may be difficult to construct because they may require interfacing aggregate models or aggregate estimates of trade flows from disaggregate models with disaggregate models of freight transport and goods vehicle traffic. This may not be possible, however, without large specification error.[1] Alternatively, aggregate modelling approaches might be considered, but as discussed previously, there may be serious deficiencies in aggregate models of goods vehicle trips. Obviously, there is no simple solution to this problem. Because it is thought that significant conceptual and empirical compromises will be involved in modelling goods vehicle traffic, experiments should probably be conducted to identify the strengths and weaknesses of alternative approaches and to assess the most promising avenues for model development.

Concluding Remarks

This study has explored the short-run relationship between the transport of goods and urban spatial structure with the aim of furthering the theoretical and empirical understanding of the determinants of goods vehicle traffic. In the course of pursuing this objective, many more questions have been raised than have been answered. It is hoped that the numerous research issues which stem from this study will be taken as a fresh challenge for others to explore this neglected area of urban tranport.

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[1]The use of aggregate variables in disaggregate models may often involve specification error (Maddala, 1977).

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