To the Graduate Council:

I am submitting herewith a dissertation written by James Denis Brogan entitled, "An Analysis of Truck Travel Demand Forecasting Techniques and Data Requirements." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Civil Engineering.

Kenneth W. Heathington, Major Professor

We have read this dissertation
and recommend its acceptance:

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AN ANALYSIS OF TRUCK TRAVEL DEMAND FORECASTING TECHNIQUES AND DATA REQUIREMENTS

A Dissertation

Presented for the

Doctor of Philosophy

Degree

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James Denis Brogan

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To Kathy, Jeremiah, and Matthew

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ABSTRACT

This study investigates a range of techniques available for use in forecasting urban truck travel demand and examines in detail the use of a specific technique--a truck trip survey at the business establishment level--for estimating localized urban truck movements. The research investigation focuses on several planning levels. Traditional methods of area-wide truck travel forecasting using multiple regression analysis in the trip generation stage are reviewed and summarized. The stratification of truck trip ends by truck type, trip purpose, and destination land use is investigated as a means of improving the regression models developed in this long-range planning area. An investigation of the use of land area truck trip rates is also made. This technique, at a somewhat lower level of analysis than the strategic planning using multiple regression techniques, may be applied to local impacts of urban truck activity. Finally, the major portion of the study is devoted to the development of establishment level truck trip generation rates—the most detailed level of analysis. A sample of specific establishment types is chosen and the truck trip rates by establishment and sub-establishment type are developed and compared. The significant independent variables used in the truck trip rate development are identified and the minimum establishment sample sizes corresponding to specified truck trip end error rates are proposed.

In the long-range planning area the use of truck trip end stratifications by destination land use is the only alternative which results in improvements over the traditional stratification by vehicle size. The use of separate truck trip end models for "industrial" and "consumer" uses is significantly better than the use of an overall truck model. The investigation of the land area truck trip rates shows tremendous variation in the developed rates, both across land use types and over the several urban areas examined. Only residential land use truck trip rates show any stability. Difficulties in this area of investigation are also caused by the lack of standardized land use categories across urban areas.

An analysis of the results of the establishment-level truck trip generation survey reveals that the developed establishment-level truck trip rates vary by both establishment and sub-establishment type as well as by establishment size. The developed rates also show wide variability across the several urban areas studied and the use of "borrowed" rates should thus be made with extreme caution. The establishment-level truck trip generation survey also shows that large establishment sample sizes are usually necessary to develop truck trip rates which fall within specified error limits. Finally, the research has shown that the establishment-level truck trip generation survey technique is relatively inexpensive and involves little effort on the part of the establishments collecting the data, particularly since some of the required information is already routinely collected by many establishments.

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CHAPTER 1

INTRODUCTION

Although the 1962 Federal-Aid Highway Act based all federal aid for highway projects in urban areas of more than 50,000 population on a ". . . continuing comprehensive transportation planning process carried on cooperatively by States and local communities . . ." (Federal-Aid Highway Act of 1962), it has only been in recent years that the comprehensiveness of the traditional planning process has come to include freight as well as passenger movements. Accordingly, the more recent Federal Highway Administration's Policy and Procedure Memorandum 50-9 states that:

> Transportation planning is concerned with all facilities used for the movement of persons and goods, including terminal facilities and traffic control systems (1969, p. 2, emphasis added).

The same memorandum further states that:

> The comprehensive character of the planning process requires that . . . estimates be made of the future demands for all modes of transportation both public and private for both persons and goods . . . (1969, p. 2, emphasis added).

Despite the federal regulations, however, many urban transportation studies have paid little more than lip service to the question of goods, and goods-vehicle, movements. Freight movement-related guidelines for urban transportation planning purposes, for instance, have been almost exclusively truck travel-oriented and even the necessity of separate truck origin-destination surveys for areas of under 500,000 population has been questioned (Urban Origin-Destination Surveys, 1973, p. 59).

Basis for the Research

The Importance of Freight Transportation

The apparent lack of attention given to planning for urban goods movements in the traditional urban transportation planning process is somewhat perplexing in view of the tremendous importance of freight transportation to the economic well-being of the nation's urban areas and to the country as a whole. On a national level, for example, the total cost of all freight transportation (both inter- and intra-city for all modes) approached 47 percent of the total estimated national transportation expenditure in 1972 (Transportation Facts and Trends, 1974, p. 3). Overall, the total cost of freight movements in 1972 represented approximately 10 percent of the nation's gross national product. An intra- versus inter-city breakdown of the above figures for truck freight shows that local truck operations amounted to $50.5 billion in 1972, up from $16.5 billion just ten years earlier. The inter-city truck freight bill, in contrast, amounted to only $41.7 billion in 1972 (Transportation Facts and Trends, 1974, p. 4). Thus, over 54 percent of the total trucking expenditure in the United States took place in urban areas.

The importance of freight transportation to urban areas, however, is much greater than the 54 percent figure cited above. For instance, additions to the urban share of the total freight bill result from the large number of inter-city hauls terminating in urban areas. Although the expenses involved in these inter-city operations are not

reflected in local totals, they most certainly augment the goods movement problem in urban areas because of their loading, unloading, sorting, and storage requrements (Fisher, 1974, p. 2). Perhaps one indication of the magnitude of the urban-related truck movement problem is the fact that urban streets, which constitute about 16 percent of the total street and highway mileage in the country, accommodated almost 43 percent of its truck vehicle-miles of travel in 1974 (Motor Vehicle Facts and Figures '76, p. 68).

The Neglect of Goods Movements in Previous Urban Transportation Planning Studies

Early disinterest in urban goods-vehicle movements is evident in several of the now-classic urban transportation planning studies conducted in the United States in the late 1950's and early 1960's. Evidencing this disinterest, the Chicago Area Transportation Study (CATS) concluded that:

> Generally . . . the patterns of automobile trips and truck trips are sufficiently alike to suggest that no special treatment of trucks will be warranted . . . (Volume I, Survey Findings, p. 51).

Similarly, the Penn Jersey Transportation Study stated that:

> Trucks . . . form a rather small percentage of vehicles on the road during peak hours and should not greatly influence location or design of new facilities planned to serve the dominant pattern of auto users (Volume I, The State of the Region, p. 92).

Goods-vehicle movements were therefore seen to be insignificant when compared to the vast number of automobile (people-carrying) movements taking place. The prevailing attitude was perhaps best summed up by one observer who explained goods-movement disinterest as follows:

> Goods are inanimate; they don't vote and they don't complain . . . .
>
> Urban goods movements take care of themselves, so to speak. Goods move in trucks and trucks move on the same right of way as automobiles (which, of course, is part of the problem) (Pignataro, Huss, and Campion, 1972, p. 52).

The Increasing Severity of Urban Truck Movement Problems

Because problems relating to truck transportation in urban areas have grown considerably worse in recent years, a renewed interest in both goods and goods-vehicle movements is now evident. Truck congestion, particularly in certain localized areas, such as central business districts, near industrial parks, and in and adjacent to major truck terminals, has become an important area of concern. This congestion caused by goods-movement vehicles arises not only from their low performance characteristics (acceleration, turning radii, and so forth) in moving traffic streams but also from their need to load and unload at curbside when inadequate off-street loading facilities exist. Lax enforcement of no parking restrictions in curb-loading zones, of course, also results in the lowering of speeds and capacities on heavily traveled urban streets.

Inefficiencies in urban truck operations due to delivery route duplications, the tremendous increase in the number of small shipments, and increased enroute and stopped-time delays, have resulted in increased costs to shippers, carriers, receivers, and, ultimately, to consumers. In the Columbus, Ohio, central business district, for example, 60 percent of the total truck vehicles are private carriers yet they deliver only about 23 percent of the total inbound shipments

by weight (Robeson and McDermott, 1974, pp. 28-29). Similarly, a study of a square mile of downtown Brooklyn, New York, which had no freight service except by truck revealed that, while 28 external trucks with an average consignment weight of 12,400 pounds could supply the area on a daily basis, it required 4,200 trucks to handle daily internal distribution. The average internal consignment weight on these trucks was only 160 pounds (Wood, 1971, p. 30).

In addition to congestion problems and efficiency questions, goods-movement vehicles are often in conflict with passenger-carrying vehicles and with pedestrians, thereby increasing overall delays and raising serious safety questions. Finally, the proliferation of large trucks has raised serious aesthetic and environmental concerns relating to fuel and energy conservation, to the presence of trucks in primarily residential areas, and to the problems of air and noise pollution. A New York study, for instance, has concluded that truck traffic in mid-town Manhattan contributes almost one-half of the area's vehicle-related air pollution and increases the average noise levels on busy city streets by 13 to 27 decibels (dBA) (Arrow, Coyle, and Ketcham, 1974, p. 83).

All of these issues--congestion, inefficiency, people/goods conflicts, environmental concerns, aesthetics--indicate the need for an increased understanding of the structure of, and the demand for, urban freight movements.

Outline of the Research

Both the past neglect of urban goods movement considerations and the comparatively minor attention given to forecasting truck movements

in the traditional urban transportation planning process suggest several significant areas of study and research. Modeling of urban commodity movements, for example, either in a manner similar to that employed in modeling passenger movements or through a production/consumption approach employing perhaps input/output analysis, is currently receiving much attention. Such sophisticated efforts, of course, require extensive commodity-related data bases which are usually lacking in all but the largest urban areas.

Goods-movement problems in small and medium-size urban areas, in contrast, are primarily truck movement problems. Hence, the emphasis may be shifted from forecasting commodity movements to forecasting truck travel demand. Both the necessity of truck movement forecasts and the reliability of existing truck movement forecasting techniques need to be established, of course, but, in addition, the development of new and more precise forecasting techniques must be given serious consideration.

Significant contributions may be made in other research areas as well. There is an increasing concern, for example, over the costs associated with traditional urban transportation planning data collection techniques. Suggesting ways of reducing data collection costs, either through improved sampling procedures or through alternative data collection techniques, may offer considerable benefits. Finally, the need for simplified forecasting procedures and for "quick response" type solutions is obvious. Procedures which are simple to employ, relatively inexpensive, and sufficiently accurate

are necessary if the urban transportation planning process is to become more responsive to current policy issues relating to urban truck and goods movements.

Objectives of the Research

This research has the following as its general goal: to improve and simplify forecasting techniques and to suggest ways to reduce data collection needs relating to truck travel demand forecasting, particularly for small and medium-size urban areas (those under 500,000 population). The emphasis is placed on smaller urban areas because it is felt that these are the areas most in need of simplified planning tools since they usually have neither the financial nor staff capabilities to utilize the more sophisticated and complex transportation modeling techniques. Moreover, as previously stated, the goods movement problems of smaller and medium-sized urban areas tend to be primarily truck movement problems; this is not necessarily true in the larger urban areas where goods movements may encompass a variety of modes (air, water, pipeline, rail) in addition to trucks, and where unique goods movement problems may exist (for example, goods distribution in the garment district of New York City).

In conjunction with the general goal of improving forecasting techniques and suggesting ways of reducing data collection needs for truck travel demand, the research also attempts to attain several specific objectives.

Objective 1: examine and evaluate existing data requirements, available data sources, and existing urban transportation planning

techniques relating to goods-movement vehicles. Among the issues addressed in attaining this objective are:

a.) What independent variables are used to predict truck trip ends at the zonal level?

b.) How reliable are these independent variables regarding:

i.) the causal link to the dependent variable (truck trip ends);

ii.) the ease with which the variables may be obtained; and

iii.) the accuracy with which the variables may be forecast?

c.) What truck trip stratifications are usually employed in developing zonal-level truck trip end regression equations (for example, separate equations for "light" and "heavy" vehicles)?

d.) What differences exist between "production" and "attraction" equations since so many truck trips are non-home based?

e.) What special considerations are given to truck trip generation for zones containing special generators such as large industrial plants and truck terminals?

The efforts toward meeting this first specific objective consist of interviews with transportation planning personnel in selected case study cities and of a literature review of existing urban transportation studies. The output is essentially descriptive, summarizing the existing state-of-the-art of truck travel demand forecasting in the traditional urban transportation planning process.

Objective 2: investigate improvements in truck trip generation techniques through truck trip end stratification.

The major thrust of this objective is to determine if the stratification of truck trip ends into discrete categories and the development of separate trip generation models for each category of stratification aids in improving the reliability of truck trip forecasts. Among the trip end stratifications which are evaluated are the following:

a.) stratification by vehicle type (for example, panel and pickup trucks, other two-axle trucks, other single unit trucks, and all combination units),

b.) stratification by trip purpose,

c.) stratification by destination land use.

Objective 3: develop truck trip generation rates for various broad land use categories.

The development of truck trip rates by land use type is accomplished by employing both the truck trip ends stratified by land use and available land use acreages by type. Use of the rates, both those developed in this research as well as those previously reported in the literature, is important as input to sketch planning level decisions and the rates may, in fact, be substitutable for more detailed planning analyses relating to truck trips.

Objective 4: develop truck trip generation models based on business establishments rather than individual vehicles as the unit of analysis.

In contrast to the traditional urban transportation planning approach to trip generation modeling which uses the vehicle as the unit of analysis and develops zonal-level regression relationships, some recent research has focused on the truck trip generating characteristics of individual establishments.

This section of the research surveys truck movements at selected establishment types and develops truck trip generation rates for those selected establishments.

The analysis of the truck trip survey by establishment type focuses on a number of specific areas. First, truck trip rates for selected establishment types--wholesale operations, downtown retail establishments, and major truck terminals--are developed. These truck trip rates are examined to determine their variation according to several criteria:

a.) variation by truck type, for example, to determine if different trip rates for "light" and "heavy" goods-movement vehicles exist;

b.) variation in truck trip rates by sub-establishment type. Different rates, for example, for wholesale grocers and wholesale hardware distributors would negate the use of truck trip rates by generalized land use categories for forecasting truck trips;

c.) variation of truck trip rates by establishment size within particular industry groupings.

A second concern in the analysis of the establishment truck trip survey is the significance of the independent variables available for truck trip rate development. In addition, a third area of

concern is the ease and completeness of the data collection effort. Proprietary information of the surveyed establishments, disclosure rules, and any unusual or unanticipated problems in collecting truck trip information at the establishment level are examined.

Finally, the establishment-level truck trip survey analysis proposes the minimum establishment sample size requirements necessary to obtain truck trip end estimates within specified error limits. Using a procedure developed for error rate analysis of automobile trips to special traffic generators, the research relates trip end error to maximum values of rate-producing variables and sample standard deviations for given confidence levels.

Benefits of the Research

A major outcome of the research is its use as a guideline for local transportation planners in small and medium-size urban areas to enable them to make more effective use of existing truck travel data as it relates to current urban planning issues. Applications of the research results exist at a number of distinct levels:

a.) an improved knowledge of network-wide commodity-vehicle movements may be realized as a result of improvements to trip generation regression procedures through additional truck trip end stratifications;

b.) local impact analyses may be refined through reliance on truck trip generation rates for both generalized land use types and selected business establishments.

Outline of the Report

Chapter 2 of the report reviews existing truck travel data requirements and forecasting methods. In meeting the requirements of objective 1 of the research, Chapter 2 examines truck travel surveys, the truck travel estimation process, particularly at the trip generation stage, and the existing use of truck trip rates by generalized land use categories.

Chapter 3 describes the state of the art of truck trip generation at the establishment level. The basic premises underlying the technique are presented and previous research on truck trip generation at this level is reviewed.

Chapter 4 is concerned with objective 2 of the research--the improvement in traditional truck trip generation techniques through trip end stratification. Stratified regression relationships are developed here and tested for improvement over the original aggregate relationships.

The developed truck trip rates by land use type are considered in Chapter 5. Land use truck trip rates are developed for several case study cities and comparisons across cities, as well as with previously reported rates, are made.

Chapter 6 deals with objective 4 of the research--the development of truck trip generation rates for selected establishment types. The survey design, the selection and description of the study areas, and the results of the data collection effort are described in the first section of the chapter. Chapter 6 also details the analysis of the establishment survey including the development of establishment truck

trip rates, the significance of the independent variables used in trip rate development, and the sample size requirements and error rates associated with the trip rates.

Finally, Chapter 7 discusses the conclusions reached and the implications of the research.

CHAPTER 2

A REVIEW OF EXISTING TRUCK TRAVEL DATA NEEDS AND FORECASTING METHODS

The traditional urban transportation planning process, of which truck travel demand forecasting is a part, is a highly formalized and somewhat rigorous procedure which attempts to relate the travel patterns existing in an urban area to the location and intensity of land use in the area, the demographic and economic characteristics of the area, and the layout of existing transportation facilities (Guidelines for Trip Generation Analysis, 1967, p. 2). Future travel in the area is then based on forecast economic and demographic characteristics for various alternative future land use and transportation system configurations.

The purpose of this chapter is to review the data needs and forecasting methods of this traditional process as they relate to truck travel. The chapter begins with a review of the truck travel surveys of the traditional process, including a discussion of the sampling techniques utilized and the survey methods employed. Next, the truck travel simulation process is discussed briefly; the familiar sequential modeling process of trip generation, trip distribution, traffic assignment, and model split is considered. Finally, a detailed review of truck trip generation analysis in the traditional process is made. This review considers zonal regression analysis including the independent variables used to predict zonal truck trip ends, the strength of the relationships developed, the truck trip end

stratifications considered, and the merits of developing both "production" and "attraction" equations for truck trip ends. The chapter concludes with a discussion of the use of truck trip generation rates for generalized land use categories; these rates may be developed from the truck origin-destination surveys if land use variables are coded for the surveyed truck trips.

Truck Travel Surveys

The primary sources of truck travel data for urban transportation planning are the three origin-destination surveys conducted as part of a comprehensive urban transportation study. Detailed guidelines for the administration of these surveys have been developed by the Federal Highway Administration (Urban Origin-Destination Surveys, 1973) and thus the approach is somewhat routine. The procedures and scope of each of the three travel surveys as they relate to truck travel are described below.

Dwelling Unit Survey

A small amount of truck travel data is obtained from the dwelling unit home interview survey, which collects household characteristics and travel information from a sample of dwelling units in the study area. Thus, for example, questions relating to the means of travel for each trip by a member of the household in the home interview survey usually include the categories "truck driver" and "truck passenger" as valid responses. The truck trips reported as part of the dwelling unit survey, however, are usually more functionally related to automobile trips since they consist primarily of

personal business-type trips in small panel, pickup, and other two-axle truck vehicles. In addition, if the subsequent external or truck survey includes a sample of personal business-type truck trips, the duplicate trips have to be removed from one survey at the editing stage of the data collection process.

External Survey

Truck travel information is also obtained from the external survey which samples trips which originate and/or are destined outside the study area but which have either one trip end in the area (external-internal or internal-external trips) or pass completely through the area (through trips).

Typically, the external survey is conducted by establishing a series of roadside interview stations along a cordon line defining the transportation study area. The stations are set up at major transportation routes crossing the cordon line and a sample of all vehicles crossing the line is selected for interviewing. Sampling rates at the external stations vary since not only a percentage of vehicles during one particular interview period must be obtained but also because personnel constraints often limit both the number of stations which may be operated on any one day and the number of hours during the day that a station may remain in operation. Typically, study guidelines suggest that minimums of 25 percent of the off-peak traffic on routes which carry less than 10,000 vehicles per day and 10 percent of peak period traffic on routes with over 10,000 vehicles per day be sampled (Urban Origin-Destination Surveys, 1973, p. 77).

External survey questions relating to truck travel usually attempt to determine vehicle type and general trip purpose (personal use or commercial use). Occasionally, the trip purpose category may be expanded in order to define further the commercial purpose of the truck trip. Land use information, particularly at the internal trip end, may also be obtained in some cases. The impracticality of a lengthy questionnaire for a roadside interview, however, precludes the obtaining of all but what is considered the most essential information. For this reason, most external surveys, particularly those conducted in smaller urban areas, have obtained little or no commodity-related information from truck interviews.

As with the dwelling unit survey, duplicate truck trips (from either the dwelling unit or internal truck survey) must be removed before final editing and processing.

Internal Truck Survey

The large majority of truck travel information is obtained from the internal truck and taxi survey, which samples a portion of the total truck population garaged in the study area. All trips made by the sampled trucks on the study day(s) are recorded and the sample is expanded to universe size to replicate total internal truck travel.

The sampling unit in the internal truck survey is thus the individual vehicle in contrast to the dwelling unit survey where all trips made by a sampled household are recorded. The sample of trucks is usually obtained by drawing a systematic random sample from a list of registered trucks in the area. Some early research has suggested

that the sampling rate for the truck survey should be about twice the home interview sampling rate (Manual of Procedures for Home Interview Traffic Studies, 1954); this guide would indicate a sampling percentage of from 5 percent for cities with populations between 500,000 and 1,000,000 to about 25 percent for a population range of 50,000 to 150,000 (Urban Origin-Destination Surveys, 1973, p.38). Variable sampling rates for large and small truck vehicles have been suggested, and minimum sample sizes of 2,000 vehicles in each sampling category have been recommended if any type of commodity information is to be obtained along with the truck movement information (Urban Origin-Destination Surveys, 1973, p.60). The larger samples are needed for commodity movement analyses because only a percentage of the trucks registered in an area travel on a given day, because only a percentage of these carry freight, and because only a percentage of those carrying freight carry more than one commodity type (Wood, 1967, p. 92).

As might be expected, the internal truck survey collects, by far, the most detailed information on truck travel of any of the origin-destination surveys. In addition to the vehicle and administrative data required for quality control and vehicle identification purposes, the internal truck survey form usually collects the following information for each trip made by the sampled truck on the survey day:

a.) trip origin and destination,

b.) land use at origin and destination,

c.) starting and ending time of the trip, and

d.) trip purpose.

Trip purposes often used include pickup goods, deliver goods, pickup and deliver goods, garage address, base of operations, service call, repairs, and personal.

Commodity information may be obtained in the internal truck survey if the needs of the study require it; this has not been the case in many previous studies. If commodity information is desired, of course, it must be collected in the external survey as well as the truck survey for a complete picture of the commodity movements taking place in the area. As with the other truck travel surveys, the internal truck survey must insure that duplicate trips are removed before expanding the sample to estimate the overall truck movement in the study area.

Truck Travel Simulation

Since the first urban transportation studies were performed in the early 1950's the procedure for forecasting travel demand in urban areas has become quite elaborate. The process, based on a series of mathematical models, has been highly computerized and detailed guidelines exist for applying the procedure to any urban area (Urban Transportation Planning: General Information and Introduction to System 360, 1972; FHWA Computer Programs for Urban Transportation Planning, 1974). Quite naturally, the emphasis of the modeling procedures is on person movement; freight movement analyses are exclusively truck-related and employ the origin-destination truck data from the three travel surveys previously described. The

modeling procedure used to forecast truck movements is an application of the sequential passenger movement modeling process of trip generation, trip distribution, and traffic assignment. Each of these procedures, as they relate to truck travel, is described below.

Truck Trip Generation

Truck trip generation attempts to project the number of truck trip ends which will originate or terminate in a particular analysis unit (usually a traffic zone). Truck trip ends are related to the type and intensity of land use in the zone as well as the population, employment, and other socioeconomic characteristics of the zone. The analytical technique which is usually employed in the trip generation stage is multiple regression analysis. Other trip generation techniques are available, however, including land area trip rate analysis and cross-classification analysis (Guidelines for Trip Generation Analysis, 1967). A detailed discussion of these techniques, and their application to truck travel demand forecasting, appears in a subsequent section.

Truck Trip Distribution

Truck trip distribution models, which calculate the trip interchange between analysis zones, are usually the same gravity-type models used in passenger trip distribution. Often, however, trucks are stratified by vehicle size and separate distribution models are developed for each truck type. Figure 2-1 shows that, when vehicles are stratified by size of truck, origin-destination trip length distributions do differ with a larger percentage of heavy trucks making

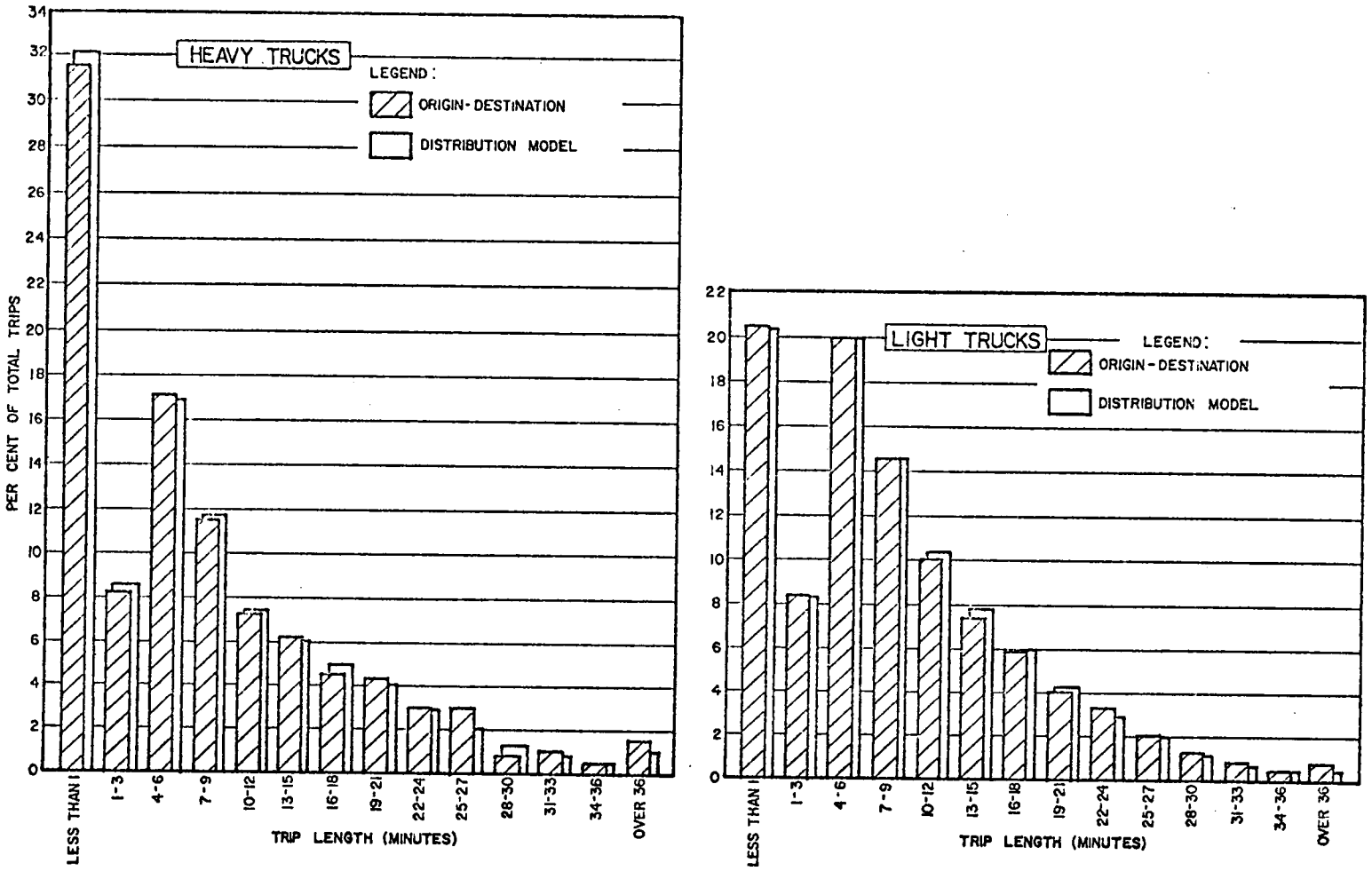


FIGURE 2-1

TRIP LENGTH DISTRIBUTION OF LIGHT AND HEAVY TRUCKS IN THE OKLAHOMA CITY AREA (1965)

Source: Wilbur Smith and Associates, Oklahoma City Area Regional Transportation Study. Prepared for Oklahoma State Highway Department. Columbia, South Carolina, 1968.

relatively short trips. The friction factors (or relative distribution rates) also differ as shown in Figure 2-2.

Truck Traffic Assignment

Only at the traffic assignment stage, where the zonal trip interchanges are assigned to specific transportation facilities, are the distributed truck trips combined with automobile trips and a total trip matrix assigned to the transportation network. Standard traffic assignment techniques are employed (Traffic Assignment, 1973) and the assigned volumes are compared to actual network vehicle counts at screenlines or on selected highway links. Usually volume counts at screenlines have not included vehicle classification counts although such information could be used in evaluating the accuracy of separate truck assignments. A separate truck assignment has been made in Louisville, Kentucky, in connection with an evaluation of truck routes (MacGillivary, 1976). A conventional minimum time path assignment was made; results, unfortunately, were unrealistic. Further research into the feasibility of separate truck assignments is, nevertheless, necessary and additional work is being performed in this area of study (Phiu-Nual, 1976).

Truck Trip Generation Analysis in the Traditional Urban Transportation Planning Process

All of the approaches used in trip generation analysis may be grouped into one of three categories (Guidelines for Trip Generation Analysis, 1967, p. iii):

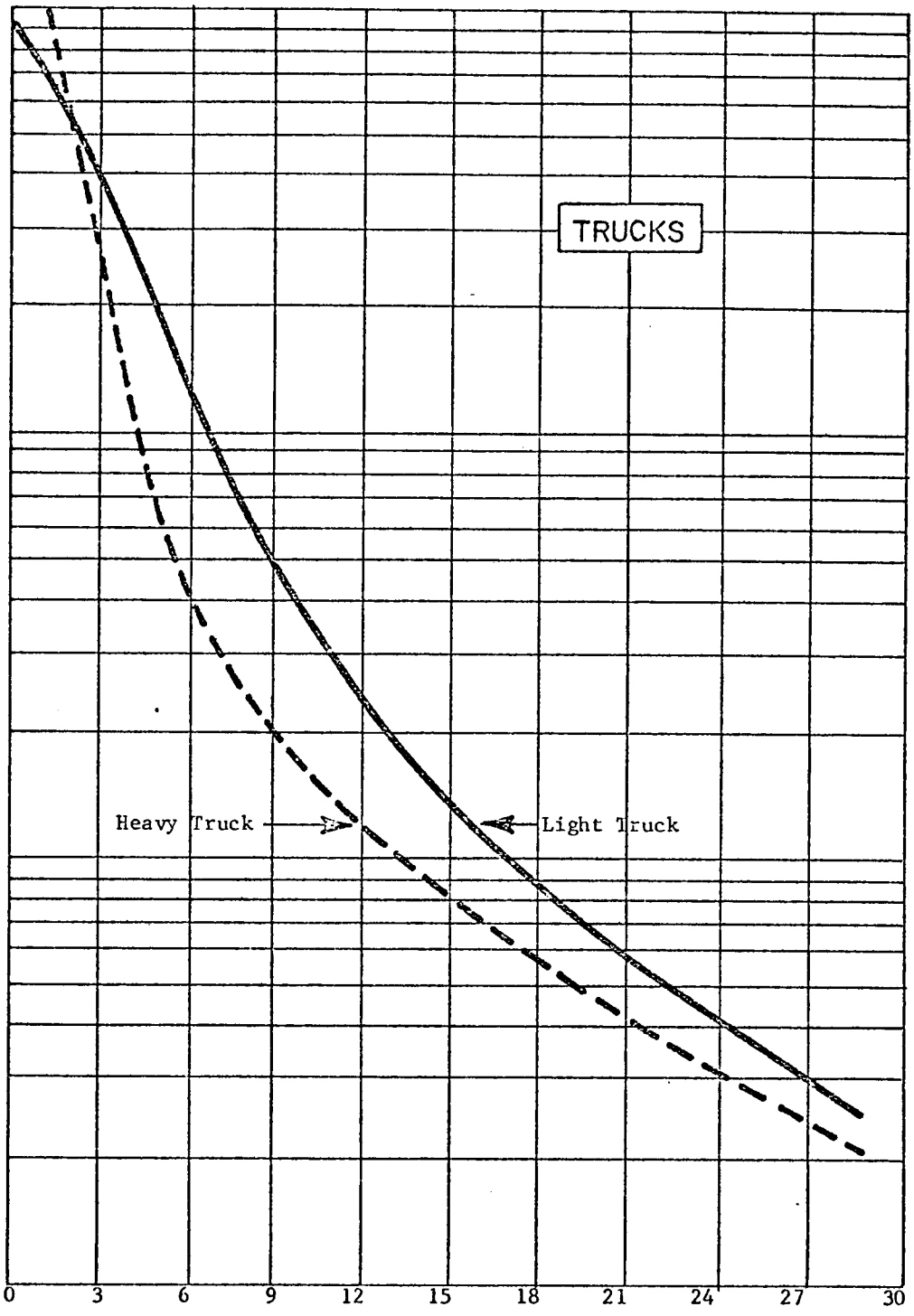


FIGURE 2-2

FRICTION FACTORS FOR TRUCK TRIP DISTRIBUTION
MODELS FOR COLUMBIA, S.C. URBAN AREA (1965)

Source: Wilbur Smith and Associates. Columbia Area Transportation Study, Prepared for the South Carolina Highway Department. Columbia, 1966.

a.) Cross-classification, or category analysis, techniques stratify the independent variables into several distinct groups creating an "n"- dimensional matrix. Averages of the dependent variable (trips per dwelling unit, for example) are then computed for each cell of the matrix and forecasts are made by summing the trip ends for the forecast proportions of the independent variables.

b.) multiple regression analysis relates zonal trip ends to various socioeconomic and demographic characteristics of the zone through a mathematical modeling procedure.

c.) land area trip rate analysis develops trip generation rates (trips per acre, for example) for the various land use categories existing in the area.

The applications of each of these approaches to truck trip generation are varied but certain techniques have been much more widely used than others. The purpose of this section is to examine the role that each of the three categories has played in the determination of truck trip generation results for urban transportation planning purposes.

Cross-Classification Analysis

Cross classification has seen limited use as a technique for truck trip generation analysis. Some early work was performed by the Puget Sound Regional Transportation Study (Cowan and Walker, 1964) and more recent federal guidelines have suggested a modified cross-classification approach for non-residential trips (Trip Generation Analysis, 1975, pp. 40-43), yet few specific applications exist.

The approach used by the Puget Sound Study for developing commercial vehicle trip generation rates was to determine commercial vehicle trips per person or per employee for various stratified residential, commercial, or industrial zonal activities. Future trip attractions were then based on forecasts of the rate-producing independent variables (Guidelines for Trip Generation Analysis, 1967, p. 24). An example of the commercial vehicle trip rates for the Seattle area is given in Table 2-1 (Trip Generation Update, 1972, p. 32) for the 19 "groups" into which the study area was divided. From this table it can be seen that commercial areas (shopping centers) and industrial areas have the highest truck trip production or attraction rates. This result is not surprising.

Multiple Regression Analysis

By far, the most widespread technique employed in trip generation analysis has been multiple regression analysis. In addition to being the most widely used technique, however, it is also perhaps the most widely abused. The advent of high speed electronic computers in the late 1950's and the subsequent development of "canned" regression programs frequently led to a reliance on the machines and their associated software to produce meaningful regression equations with little or no forethought on the part of the analyst. As a result, regression equations for trip generation analysis, while statistically correct and computationally accurate, were often cumbersome and intuitively illogical.

Essentially, multiple regression analysis seeks to analyze a relationship which may exist between a dependent variable (truck trip

TABLE 2-1

COMMERCIAL VEHICLE TRUCK TRIP RATES, PUGET SOUND AREA
(1972)

Group	Area Covered	Trip Production or Attraction Rate
	Predominately Residential Zones	Per Person for Total Zonal Population
1-2	Pierce County	0.10 - 0.19
3-5	King County	0.10 - 0.18
6	Kitsap County	0.11
7	Snohomish County	0.10
	Predominately Employment Zones	Per Employee for Total Zonal Employment
8-10	Seattle, Tacoma, Everett, Bremerton CBD's	0.22 - 0.64
11-13	Industrial Areas	0.10 - 0.80
14	Community Centers	0.42
15-18	Shopping Centers	0.70 - 2.08
19	Colleges, Hospitals, and Military Installations	0.43
Special	Sea-Tac Airport	0.54[a]

Source: Trip Generation Update, Puget Sound GC, 1972, p. 32.

[a]This rate is applicable to employment which can attract commercial vehicle trips only. Such employment is about 2/3's of the total employment in this zone.

productions per zone, for example) and several independent variables. The ultimate purpose of the regression procedure, which determines a line of best fit for the data according to a least squares criterion, is to employ future values of the independent variables to predict future trip ends.

Because the regression procedure is mathematically based, certain statistical tests may be performed to evaluate the significance of the overall regression, the significance of each independent variable in the regression equation, and the total amount of variation in the data which is "explained" by the regression relationship. The relationships must also be examined, however, for reasonableness of results, and more importantly, for the applicability of the independent variables and the accuracy with which they may be forecast.

Typical examples of the regression relationships developed for truck trip generation are shown in Table 2-2. It can be seen that the earlier equations were quite complex, involving not only a variety of independent variables which may be difficult to forecast and could possibly have high intercorrelations, but which also, in some cases, made little sense from a "reasonableness" standpoint. The separate equations for light, heavy, and external trucks for example, all contain "school enrollment" as an independent variable used to forecast truck trip ends. Intuitively, this variable makes no sense when used to predict truck trips but suggests that school enrollment is perhaps a surrogate for another independent variable such as total population.

TABLE 2-2

TYPICAL TRUCK TRIP GENERATION EQUATIONS FOR ZONAL PRODUCTIONS AND ATTRACTIONS

Study Area And Year	Regression Equations	R^2	Standard Error of Estimate / Mean	Remarks
Winston-Salem NC 1965	Light Trucks = 0.09 (Population) + 0.24 (Dwelling Units) + 0.12 (Employment - white collar) + 0.06 (Employment - blue collar) - 0.24 (School Enrollment) + 0.02 (Retail Sales - convenience) + 16.22	0.62	61%	Truck equations apply to both attraction and production trip ends.
	Heavy Trucks = 0.04 (Population) + 0.07 (Dwelling Units)- 0.16 (Cars) + 0.19 (Labor Force - white collar) + 0.18 (Employment - blue collar) - 0.08 (School Enrollment) + 13.30	0.40	132%	
	External Trucks = 0.75 (Cars) - 0.57 (Labor Force - blue collar) + 0.86 (Employment - white collar)+ 0.82 (Employment blue collar) - 0.18 (School Enrollment) + 0.02 (Retail Sales - convenience) + 0.05 (Retail Sales - general) - 1.97	0.72	74%	External equation applies to attraction trip ends.

TABLE 2-2 (continued)

Study Area And Year	Regression Equations	R^2	Standard Error of Estimate / Mean	Remarks
Richmond VA 1974	Truck Productions or Attractions = 43.84 + 0.180 (Internal Employment) + 0.370 (Dwelling Units)	0.59	46%	

Sources: Wilbur Smith and Associates. Statistical Evaluation Mathematical Trip Distribution Model and Regression Analysis. Winston-Salem Area Transportation Study, July 1965, Appendix Table 13; Virginia Department of Highways and Transportation. Richmond Regional Study Area Transportation Study, Level II Review, Trip Generation, 1974, p. 4.

The heavy and external truck equations both contain the independent variable "cars." The relationships are quite different, however, since an increase in the number of cars in the heavy truck equation results in a decrease in the number of truck trip ends while the opposite is true for the external equation. Again, cars may be substituting for another variable but the complexity of intercorrelations makes the true relationships difficult to determine.

The 1974 equation for Richmond reflects the continuing trend toward simplification in the multiple regression approach to truck trip generation analysis. One equation is used for all internal trucks and, since the majority of truck trips are non-hcme based, the same equation applies to both "production" and "attraction" (or origin and destination) truck trip ends. The equation itself, moreover, is quite simple with only two independent variables present, both of which are relatively easy to forecast. Finally, the statistical adequacy of the relationship as measured by the coefficient of multiple determination (R^2) and the standard error of the estimate as a percentage of the mean, is not only quite acceptable, but in some respects is better than that obtained from the more complex Winston-Salem equations.

A fairly complete survey of multiple regression equations used for truck trip generation analysis in previous urban transportation studies is given in Appendix A. In addition to showing the constants, coefficients and variables used in the equations themselves, this Appendix shows, where possible, the statistical adequacy of the equations and any comments relating to trip stratifications or the

elimination of unique analysis zones. Each of the items listed in detail in the Appendix is summarized below.

Variables Used in Regression Analyses. The independent variables which appear most often in the truck trip generation equations in Appendix A may be grouped into three distinct categories: employment variables, household-related demographic variables, and floorspace and acreage variables. The most widely used employment variable, by far, is total zonal employment. Other employment variables which show up with some regularity are various manufacturing, retail, and wholesale employment categories. Less frequently used employment variables include agriculture and mining employment, "blue collar" employment, and "white collar" employment.

The predominant household-based demographic variable in the truck trip generation equations apparently is the number of dwelling units per zone although this variable does not show up as frequently as total employment. Other important demographic variables include total population (a surrogate for dwelling units), and total zonal labor force. Less logical independent demographic variables include total cars owned, zonal school enrollment, and the number of auto trip ends per zone.

Floorspace and other establishment-related independent variables appear less frequently than either the employment or demographic household-related variables. Retail floorspace shows up regularly, however, as do commercial floorspace and total retail sales. Less frequent establishment-based variables include industrial, office, and residential floorspace measures as well as the total number of

garaged trucks on a zonal level.

In general, it can be said that the recent trend has been away from using a large number of independent variables in the regression equations. Floor area variables are seen less frequently in the more recent expressions, moreover, and the emphasis is now being placed on population and employment variables which may be somewhat easier to predict.

Strength of the Regression Relationships. Two measures of the statistical "strength" of a multiple regression equation are the coefficient of multiple determination (R^2--which measures the amount of total variation in the dependent variable which may be explained by the independent variables in the regression equation beyond that which could be explained by the mean of the dependent variable) and the standard error of the estimate as a percentage of the mean of the dependent variable (which is an indication of how precisely values of the dependent variable may be estimated by the independent variables in the equation). Values of R^2 may thus range from 0.0 (all variance unexplained) to 1.0 (no variance unexplained) and the standard error of the estimate as a percentage of the mean may take any value greater than zero (no dispersion from the regression line). As an example, a value of 100 percent for the standard error of the estimate as a percentage of the mean would place about 68 percent of all observations within plus or minus the mean value of the true value of the dependent variable.

An examination of the statistical adequacy of the regression equations in Appendix A shows that the values of R^2 generally fall

within the range of 0.27 to 0.85. Very little can be generalized from this--except to say that the equations are not explaining a high percentage of the variation in most cases. Tradeoffs do exist, however, as each independent variable added to the equation explains a bit more of the variance at the expense of adding an additional variable to be forecast. The value of R^2 increases as additional independent variables are added to the equation, then, but as the number of variables approaches the number of observations, the value of R^2 will approach 1.0. The R^2 values may also be increased, moreover, by deleting zones with unique characteristics and thus reducing the overall variation. For this reason, little comparison may be made between the R^2 values shown in the Appendix.

The same problem arises in any evaluation of the standard error of the estimate as a percentage of the mean. Ideally, the smaller this value is, the better the equation is. In reality, however, the standard error of the estimate may be reduced either by adding additional independent variables to the equation or by deleting unique zones from the analysis.

The equations shown in Appendix A have percent standard error values of from 184 percent to 32 percent. Again, little comparison can be made because of the unique nature of the equations. Nevertheless, some guidelines do exist for values of percent standard error. The Pueblo, Colorado Area Transportation Study, for example, used an initial maximum of 40 percent for the value of the standard error of the estimate as a percent of the mean; this figure was later adjusted to 100 percent after the development of the

regression equations showed the initial value to be unreasonable (Reevaluation of the Trip Generation Equations, 1974, p. 12). If either standard is applied to the equations in Appendix A, a significant number of the relationships are of questionable validity.

Stratifications Considered in The Regression Equations. The traditional stratification method employed in the truck trip generation equations in Appendix A is to develop three separate equations for: internal light trucks, internal heavy trucks, and total external trucks. Light trucks are usually defined as all two-axle, four-wheel truck vehicles and heavy trucks as all other commercial vehicles.

A few stratifications other than those by "light" and "heavy" categories do exist. One study, for example, creates an additional truck type by further stratifying all trucks, except panels and pickups, into "medium" and "heavy" categories. Another study has developed separate equations for unique geographical locations in the study area and a third study has stratified external truck trips into those made by residents and those made by non-residents. For the most part though, the "light" and "heavy" categories are the only ones on which stratification is based. Many of the studies do not even make this light and heavy distinction and consequently develop equations only for total internal and total external truck trips.

Use of "Production" and "Attraction" Equations. Since the great majority of truck trips are non-home-based, there would seem to be little merit in developing separate equations for trip productions

(those trips "produced by" a zone) and trip attractions (those trips "attracted to" a zone). The futility of such an effort is borne out by an examination of Appendix A which shows very little difference between production and attraction (or origin and destination) equations for those few studies which developed separate equations. Most studies either used one equation to estimate both productions and attractions or developed one equation which would estimate either productions or attractions.

Land-Area Truck Trip Rate Analysis

The third approach to truck trip generation analysis has been the development of truck trip rates, usually truck trip ends per acre, for the general land use types existing in an urban area. The application of the developed land area truck trip rates rests not so much in the long-range, strategic-type, planning on a region-wide, urban, or even network-wide basis, but rather in the short-run, tactical planning area. This approach thus has merit on a local level and may prove valuable in the analysis of the impact of major truck generating activities in localized sections of an urban area.

Because of the short-term application of land area trip rate analysis and the traditional long-range orientation of the conventional transportation planning process, few applications of the land rate approach have previously been made. With the recent emphasis on short-term planning, however, and the renewed interest in small urban area planning, this technique seems to have considerable value.

Several examples of truck trip rates by land use from different urban areas are shown in Table 2-3. It can be seen that commercial land use generates, by far, the greatest number of truck trips per acre, while residential uses generate the fewest (and also have the most stability across cities).

A breakdown of land area truck trip rates in Nashville, Tennessee, by truck type (light versus heavy) is shown in Table 2-4. Once again, the commercial land use category has the highest rates, both overall as well as for each truck type. Industrial land uses also generate a significant number of heavy truck trips while a large proportion of the residential truck trips, on the other hand, is made by light truck vehicles.

A final, more recent example of the application of the land area trip rate approach is given in Table 2-5 which summarizes truck trip generation rates for the Chicago region. As might be expected, commercial land uses, while representing only 3.5 percent of the developed land in the study area, account for over 37 percent of the total truck trips. Manufacturing land uses account for another 12 percent of the truck trips and only an additional 4.4 percent of the developed land. Residential land uses, on the other hand, while accounting for almost 35 percent of the truck trips, also consume over 35 percent of the developed land and thus have a relatively small truck trip rate.

Drawbacks to the land area trip rate approach to truck trip generation analysis include the generalized nature of the land use categories, which allows for a wide variation of rates within

TABLE 2-3

DAILY TRUCK DESTINATION TRIP ENDS PER ACRE BY LAND USE

Land Use	Destination Trip Ends Per Acre					
	Monroe (96.6)[a]	Columbia (196.0)	Little Rock (222.9)	Baton Rouge (245.1)	Richmond (417.6)	Average
Residential	1.7	1.2	1.0	2.0	1.4	1.46
Manufacturing	5.9	1.5	0.4	1.3	2.6	2.34
Transportation - Warehouse	2.5	2.3	NA[b]	4.0	0.9	2.42
Retail - Wholesale Trade	35.0	20.3	16.0	33.6	10.3	23.04
Services, Schools Government	5.2	3.2	NA	2.6	4.0	3.75
ALL DEVELOPED LAND	3.5	2.2	0.6	0.9	2.0	1.84

Source: Wilbur Smith and Associates. Motor Trucks in the Metropolis. Under commission from the Automobile Manufacturers Association. New Haven, Ct., August, 1969, p. 65.

[a]Urban area population in thousands.

[b]Not applicable.

TABLE 2-4

TRUCK TRIP GENERATION BY LAND USE AND TRUCK TYPE
IN NASHVILLE, TENNESSEE
(1959)

Destination Land Use	Truck Destinations Per Acre		
	Light Trucks	Heavy Trucks	All Trucks
Residential	0.74	0.18	0.92
Industrial	1.26	1.25	2.51
Transportation, Communication, Utilities	0.48	0.48	0.96
Commercial	10.12	4.68	14.80
Public Land & Buildings	0.27	0.25	0.52
Other	0.016	0.016	0.032
All Land Uses	0.42	0.19	0.61

Source: Wilbur Smith and Associates. Nashville Metropolitan Area Transportation Study. Volume I, Origin Destination Survey and Major Route Plan. New Haven, Ct., 1961, p. 60.

TABLE 2-5

TRUCK TRIP GENERATION RATES BY LAND USE CATEGORIES
IN THE CHICAGO AREA

Land Use Type	Land Area (Acres)	Percent of Total Land	Percent of Developed Land	Total Truck Trips	Percent of Trips	Truck Trips Per Acre
Residential	335,307.1	11.3	35.8	428,941	34.8	1.28
Manufacturing	41,532.2	1.4	4.4	149,916	12.2	3.61
Commercial	32,449.6	1.1	3.5	462,380	37.6	14.25
Public Buildings	78,933.7	2.7	8.6	31,545	2.6	.40
Public Open Space	144,885.2	4.9	15.5	4,733	0.4	.03
Transportation, Communication, Utilities	99,813.0	3.4	10.8	111,338	9.0	1.12
Highways-Streets	181,174.3	6.1	19.4	26,076	2.1	.14
Auto Parking	3,762.2	0.1	0.3	1,835	0.1	.49
Total Developed	939,017.4	(31.5)	100.0	1,216,757	(98.8)	1.30
Undeveloped	2,034,632.8	68.5		14,431	1.2	.007
Total	2,973,650.2	100.0		1,231,188	100.0	.41

Source: David A. Zavattero, "Commercial Vehicle Trip Generation in the Chicago Region," unpublished report, Chicago Area Transportation Study, June, 1975, p. 6.

categories themselves and across urban areas. Truck trip rates may also vary within land use categories according to the geographical location of the land use in the study area. Light truck trip rates for commercial land uses in the Nashville area, for example, ranged from about 25 light truck trip destinations per commercial acre in the central business district (CBD) to approximately three light truck trip destinations per commercial acre at a distance of eight miles from downtown (Nashville Metropolitan Area Transportation Study, 1961, p.59).

Summary

This chapter has reviewed the forecasting techniques, survey methods, and data needs of the traditional urban transportation planning process as they relate to truck travel. The three travel surveys which collect truck movement data have been described and portions of the truck travel simulation process have been discussed briefly.

Truck trip generation analysis, which attempts to relate the number of truck trip ends produced in or attracted to an area to the characteristics of that area, has been described in detail. Three approaches to truck trip generation analysis have been considered. Cross-classification, or category analysis, attempts to forecast future trip ends based on various stratifications of the independent variables. Regression analysis, until recently the most widely used trip generation technique, attempts to use mathematical models to relate zonal truck trip ends to independent zonal variables. Finally, land area trip rate analysis tries to develop truck trip rates, usually on a per acre or per square mile basis, for each of the various land use types in an area.

A summary of the three trip generation approaches shows that regression analysis is moving toward more simplified models with more emphasis on the reasonableness of the relationships and the ease with which the independent variables may be forecast rather than improving the statistical fit of the relationships. For local impact analysis, as well as for quick response solutions and small urban area planning, however, the land area trip rate analysis method seems to be the most applicable approach.

CHAPTER 3

TRUCK TRIP GENERATION AT THE ESTABLISHMENT LEVEL--THE STATE OF THE ART

The traditional urban transportation planning approach applied to truck travel demand forecasting, as described in Chapter 2, uses the truck vehicle as the individual unit of analysis and collects data on the movements of sampled trucks within the study area. Some recent research, however, has focused on the truck trip generating characteristics of individual establishments. This method is comparable to the traditional home interview origin-destination survey procedure for passenger travel which uses the household, rather than the individual traveler, as the unit of analysis.

The purpose of this chapter is to review the existing research on truck trip generation at the establishment level. Advantages of the establishment method, compared with the individual vehicle method of analysis, will be described and the applications of establishment level analysis will be discussed. Finally, a comprehensive review of pertinent research on commercial vehicle trip generation at the establishment level will be made.

Establishment-Level Analysis

The Establishment Versus the Vehicle as a Unit of Analysis

One of the most pronounced trends in urban passenger movement demand forecasting in recent years has been the development of

"disaggregate" or "behavioral" models for analyzing urban travel demand (Kannel, 1972; Charles River Associates, 1972). The use of these household level models, rather than the more traditional traffic zone-level "aggregate" models, has merit for several reasons:

a.) casual relationships which relate to the individual travel decision may be more readily understood at the household level;

b.) sampling variability may be reduced through the elimination of the use of zonal averages in the modeling process; and,

c.) sample size requirements may be reduced considerably (Kannel, 1972, pp. 153-155).

The disaggregate modeling approach is most readily applied to passenger travel demand forecasting since the passenger travel data is initially obtained on a disaggregate, or household, level. The comparable unit of analysis for truck travel demand forecasting is the individual establishment which is producing or attracting the truck trips. Thus, truck travel data by establishment type is necessary in order to employ the disaggregate modeling approach in the analysis of truck travel demand.

Truck travel information, unfortunately, is not usually collected at the establishment level. Instead, as outlined in Chapter 2, the usual method of collecting truck travel data is by choosing a sample of truck vehicles from a list of all trucks registered in the study area. This method of sample selection, while obtaining an adequate sample of truck vehicles to replicate area-wide truck movements, does not enable the analyst to evaluate localized truck-related problems. Even on a systems-wide level, moreover, the vehicle-based unit of

analysis method seriously limits the use of trip generation techniques other than multiple regression analysis. Cross-classification, or category analysis, for example, may have application in truck trip generation analysis if the data is available on an establishment, rather than on an individual vehicle, level.

Advantages of the Establishment Method of Truck Travel Data Collection

Advantages of the "establishment" method of truck travel demand forecasting have been pointed out by many authors writing on the urban goods movement problem. Watson, for example, proposes a "disaggregate" approach to urban goods and truck movement analyses and argues that, since so little is known about the nature and demand for urban goods and truck movements, such an extremely detailed approach to the problem is necessary (Watson, 1975, p. 14). Similarly, a recent report of a study group on urban goods movement planning and modeling recommends a disaggregate approach to the development of truck trip generation models using establishments as the basic level of analysis. It was felt, moreover, by members of the group that a truck trip generation model using establishments as the unit of analysis has relatively low application costs and a favorable cost/effectiveness ratio for certain specific applications ("Assessment of Planning and Modeling Methodologies in Urban Goods Movement," 1976, pp. 64, 69).

As previously stated, the use of establishment-level truck travel data permits the use of cross-classification methods of truck trip generation analysis to be employed. Through the stratification

of truck trip generating establishments by establishment size and/or establishment function, for example, truck trip rates may be developed for each "cell" in the cross-classification matrix. In addition to allowing for a relaxation of the statistical assumptions necessary for regression analysis, the cross-classification technique also may result in the use of independent variables which are more easily forecast.

Finally, establishment level truck trip rates may be more applicable for planning purposes than truck trip rates by generalized land use categories. Shuldiner (writing of total vehicle trip generation) thus states that:

> . . . major categories of land use are too general (for trip estimation) and include too many unrelated uses . . . these broad designations are too far removed from the activities which take place upon them and which are the reasons for which trips to a given use are made (1966, p. 84).

Some degree of caution must be exercised in the use of truck trip rates by detailed establishment types, however, since difficulty in forecasting increases tremendously as the number of categories becomes large.

Applications of Establishment Level Truck Trip Generation Analysis

Significant applications of truck trip generation rates by establishment type exist in two areas. These are:

a.) the analysis of truck congestion and other truck-related problems at or near major truck trip generators (local impact analysis);

b.) the development of meaningful off-street loading and

unloading space requirements for inclusion in zoning ordinances and building regulations.

Each of these application areas is discussed below.

Local Impact Analysis of Truck Traffic. Truck traffic congestion has long been recognized as a localized, as opposed to a regional, phenomenon which exists in almost all cities, regardless of size. Sullivan (1974, p. 112) argues that the truck traffic problem should be approached at a level commensurate with the problem's scale. This approach usually requires truck trip generation studies by establishment type; the emphasis is consequently on the truck stops, or origins and destinations, rather than on the truck trips themselves.

Information from the truck trip generation rates of selected establishments could be used by local planners either to evaluate the traffic impact of such major truck generators before they are actually constructed or to recommend site locations for such facilities where the generated truck traffic would have minimal impact. Truck trip rate information by establishment type could also be useful to traffic engineers concerned with questions of intersection and local street design near large truck generators. Environmental planners, on the other hand, could utilize the truck trip generation rates in the evaluation of air and noise pollution impacts associated with major truck generators.

Development of Loading Space Standards. The second major application of truck trip generation rates by establishment type is in the development of standards for off-street loading and unloading

facilities for truck delivery vehicles. This application has particular importance in congested downtown areas where truck traffic may be a significant problem due both to the older street network which is often unsatisfactory for the movement of truck traffic and to the lack of off-street loading facilities in existing buildings which often forces deliveries to be made from the street.

A survey by the Texas Transportation Institute of off-street loading requirements for office buildings in the zoning ordinances of selected cities revealed a wide variety of requirements. One conclusion of the study, which showed, for example, a range of from 3.0 to 18.0 loading spaces for a gross floor area of one million square feet, was that the existing ordinances usually required an inadequate number of off-street loading spaces, particularly in the downtown areas (Christiansen and Holder, 1974, pp. 5-6).

Whitlock and Schoon (1972) have also studied the loading/unloading requirements of office and retail complexes. Their study, which examined relatively large facilities in both downtown and suburban locations, recommended that standards of 1.0 off-street loading spaces per 10,000 square feet of gross office floor area and 1.4 off-street spaces per 100,000 square feet of gross floor area be developed for small buildings and large complexes, respectively.

Previous Research on Truck Trip Generation at the Establishment Level

A considerable amount of research on truck trip generation at the establishment level has been performed, particularly in Great

Britain and Canada. Most existing research, however, has concentrated on the truck trip generating characteristics of the industrial sector; it has only been in the last several years that other sectors of the economy have come under serious study. The purpose of this section is to discuss previous significant work on truck trip generation at the establishment level. The studies discussed below are listed chronologically with all the industrial-related studies first.

Starkie (1967; Watson, 1975, pp. 19-22)

Starkie attempted to develop relationships between daily commercial vehicle trips and total employment for 77 manufacturing establishments in Medway Towns, England. An initial examination of the data, without regard to the industrial establishment type, suggested a non-linear relationship. A comparison of linear and logarithmic regression equations, shown in Table 3-1, suggested that without a breakdown by industrial establishment type, a simple linear regression model using plant employment would be of little use in predicting commercial vehicle trips. The use of a logarithmic expression, on the other hand, significantly improved the model and suggested that plant size was an important variable in explaining commercial vehicle generation at manufacturing plants.

Starkie next examined subsets of the sample of manufacturing plants by stratifying the establishments by Standard Industrial Classification (S.I.C.) Orders. An example of the stratified results, for 37 engineering and allied trade establishments, is shown in Table 3-2. This table reveals that stratification by establishment type does result in improved models; a non-linear relationship, however, is still very much evident.

TABLE 3-1

COMMERCIAL VEHICLE TRIPS VS. EMPLOYMENT FOR ALL MEDWAY TOWNS MANUFACTURING ESTABLISHMENTS (1964)

Regression Equation	No. of Observations	r^2	Standard Error of Estimate / Mean
(Commercial Vehicle Trips)= 26.9624 + 0.0377 (Employment)	77	0.2463	110%
Log (Commercial Vehicle Trips)= 0.2568 + 0.5595 Log (Employment)	77	0.5357	24%

Source: D.N.M. Starkie. "Intensity of Commercial Traffic Generation by Industry." Traffic Engineering and Control, January, 1967, p. 558.

TABLE 3-2

COMMERCIAL VEHICLE TRIPS VS. EMPLOYMENT FOR MEDWAY TOWNS ENGINEERING AND ALLIED TRADE ESTABLISHMENTS (1964)

Regression Equation	No. of Observations	r^2	Standard Error of Estimate / Mean
(Commercial Vehicle Trips)= 21.8256 + 0.0343 (Employment)	37	0.5992	67%
Log (Commercial Vehicle Trips)= 0.4010 + 0.4996 Log (Employment)	37	0.8661	11%

Source: D.N.M. Starkie. "Intensity of Commercial Traffic Generation by Industry." Traffic Engineering and Control, January, 1967, p. 559.

Starkie concluded that both the size of the establishment and the manufacturing type are important variables in determining commercial vehicle trip generation at manufacturing plants. He criticizes most traditional transportation studies for assuming that:

a.) all subgroups of a generalized land use category exhibit similar trip generation characteristics;

b.) the size of a trip generating unit is not an important variable in commercial vehicle trip generation; and,

c.) the relationship between produced commercial vehicle trips and various land use characteristics is linear.

Maltby (1970)

Maltby, in investigating both work (automobile) and non-work (commercial) traffic at 23 manufacturing establishments in Sheffield, England, attempted to evaluate further similarities in commercial vehicle trip generation rates between different manufacturing types. The Maltby study, in addition, attempted to investigate the relationship between truck trip generation rates and establishment size.

Non-work commercial traffic was divided into two categories--generations (the movement of a plant vehicle to an outside destination), and attractions (the movement of an outside vehicle to a destination inside the plant). Truck trip rates per 100 employees for each of these movements for three S.I.C. groupings are shown in Table 3-3.

A further analysis of the commercial vehicle trip rates was attempted using simple linear regression techniques. Results of this analysis showed that neither total plant employment nor total plant

TABLE 3-3

COMMERCIAL VEHICLE TRIP RATES PER 100 EMPLOYEES
AT MANUFACTURING PLANTS IN SHEFFIELD, ENGLAND
(1967)

Standard Industrial Classification	Type of Movement	Number of Movements per 100 Employees
Steel Manufacturing (under 1000 employees)	Commercial Vehicle Attractions	10.8
	Commercial Vehicle Generations	0.8
Steel Manufacturing (over 1000 employees)	Commercial Vehicle Attractions	9.0
	Commercial Vehicle Generations	1.4
Tool Manufacturing Plants	Commercial Vehicle Attractions	5.9
	Commercial Vehicle Generations	1.2

Source: D. Maltby. "Traffic at Manufacturing Plants." Traffic Engineering and Control, June, 1970, p. 74.

floorspace was highly significant when used to forecast total commercial generations or attractions; employment, however, was the more accurate of the two variables used. On the other hand, when individual regression equations were used to predict commercial vehicle attractions for the two manufacturing subgroups (all steel manufacturing and tool manufacturing), only total floorspace resulted in a common model.

Redding (1972; Watson, 1975, p. 22)

Further examination of the truck trip generation characteristics of industrial establishments has been made by Redding, who has investigated truck trips emanating from electrical engineering and clothing industries in northwest London. The survey methods employed by Redding were somewhat unique in that his was probably the first establishment survey to collect more than one day's traffic movements. In addition, Redding relied on the plant operators, rather than employing an outside survey crew, to record the traffic movement data.

Truck trip generation rates developed by Redding are shown in Table 3-4. The London rates shown in the table are compared to rates for similar industrial categories in Manchester (Miller and Mellon, 1970).

Results of multiple regression analyses conducted by the Redding study indicated that truck trip generation at the selected establishments was most readily explained by using either total floorspace or total employment as an independent variable. These two variables, however, exhibited high colinearity, with employment being preferable to floorspace. Other independent variables, such as manufacturing

TABLE 3-4

COMMERCIAL VEHICLE TRIP RATES PER 1000 SQUARE FEET OF FLOOR AREA AT INDUSTRIAL LOCATIONS IN LONDON AND MANCHESTER, ENGLAND (1969)

1968 Standard Industrial Classification	Commercial Vehicle Trips per 1000 ft^2 of Floor Area
Electrical Engineering Industry (London)	2.16
Electrical Engineering Industry (Manchester)	3.30
Clothing Industry (London)	4.90
Clothing Industry (Manchester)	6.85

Source: B. G. Redding. "Traffic Generated by Industrial Premises in London." Traffic Engineering and Control, August, 1972, p. 171.

floorspace, number of operatives, and number of goods vehicles owned had little significance in the regression relationships.

Redding concluded that truck trips from the particular establishments under study could best be expressed as individual truck trip rates or by simple linear regression equations utilizing either total floorspace or total employment as the independent variable. There is further indication in the Redding study that, although employment may be a somewhat better explanatory variable than floorspace (from a statistical standpoint), the latter may be preferred as it is ". . . found more frequently in applications for planning permission" (Redding, 1972, p. 173).

Kardosh and Hutchinson (1972; Hutchinson, 1974, pp. 402-424)

A one-day truck trip generation study of approximately 240 manufacturing industries in Metropolitan Toronto has been performed by Kardosh and Hutchinson. Once again, multiple regression analysis was employed to relate the total trucks produced by or attracted to the establishments to various characteristics of the establishments such as employment totals by type, manufacturing man-hours per year, raw material inputs for manufacturing, yearly fuel and electricity consumption, and total sales.

Results of the regression analysis for all industry groups combined are shown in Table 3-5. Total private trucks owned by the firm is seen to be the only independent variable of significance. The authors admit, however, that the sample of establishments may have been biased in favor of those establishment types which tend to own and operate large truck fleets such as food and beverage producers,

TABLE 3-5

INDUSTRY-WIDE TRUCK TRIP GENERATION EQUATIONS
TORONTO (1971)

Regression Equations	r^2
(Daily Truck Trip Productions)= 11.4 + 1.53 (Total Private Trucks Owned)	0.807
(Daily Truck Trip Attractions)= 12.5 - 0.86 (Total Private Trucks Owned)	0.532

Source: B. G. Hutchinson. "Urban Goods Movement," in Principles of Urban Transport Systems Planning. Washington: Scripta Book Company, 1974, p. 416.

newspaper publishers, and ready-mix concrete plants. In any event, the total industry equations may be difficult to employ for predictive purposes because of problems associated with forecasting the independent variable.

Kardosh and Hutchinson also attempted to develop truck trip generation equations for various industry subgroups. Results of this analysis are shown in Table 3-6. Again, although employment variables did enter some of the stratified equations, private trucks owned was the dominant independent variable. The statistical validity of the equations is somewhat low and the difficulty of forecasting the independent variable still exists.

Kardosh and Hutchinson summarize by stating that improved statistical validity of the truck generation equations may result from analyses of data collected over a period longer than one day since

TABLE 3-6

TRUCK TRIP GENERATION EQUATIONS BY INDUSTRY GROUP
TORONTO (1971)

Industry Group	Regression Equations	R^2
Food & Beverage	$\log_e$(Daily Truck Trip Productions)= 2.62 + 0.33 $\log_e$ (Private Trucks)	0.656
	(Daily Truck Trip Attractions)= 2.24 + 0.10 (Male Manufacturing) + 0.39 (Private Trucks)	0.715
Paper and Allied Products	$\log_e$(Daily Truck Trip Productions)= 0.74 + 0.43 $\log_e$ (Total Office Employees) + 0.22 $\log_e$ (Private Trucks)	0.600
	(Daily Truck Trip Attractions)= 7.03 + 0.07 (Male Manufacturing)	0.293
Printing, Publishing	$\log_e$ (Daily Truck Trip Productions)= 1.05 + 0.28 $\log_e$ (Male Manufacturing) + 0.51 $\log_e$ (Private Trucks)	0.883
	$\log_e$ (Daily Truck Trip Attractions)= 2.29 + 0.26 $\log_e$ (Private Trucks)	0.418
Machinery	$\log_e$ (Daily Truck Trip Productions)= 1.11 + 0.32 (Total Office Employees)	0.190
	(Daily Truck Trip Attractions)= 4.54 + 0.13 (Total Office Employees) + 1.50 (Private Trucks)	0.751

Source: B. G. Hutchinson. "Urban Goods Movement," in Principles of Urban Transport Systems Planning. Washington: Scripta Book Company, 1974, p. 417.

commodity movements seem to have little day-to-day stability. The authors also feel that separate analyses of truck movements by truck type, given adequate sample sizes, could result in improved relationships.

Leake and Gan (1973; Watson, 1975, pp. 24-27)

Truck trip generation characteristics for selected "industrial" groups have also been studied and reported by Leake and Gan for the West Riding of Yorkshire, England. Five Standard Industrial Classification (S.I.C.) groups were selected for study: road haulage contracting; wholesale distribution--food and drink; wholesale distribution--non-food products; coal, builders' materials, grain, and agricultural supplies; and other industrial materials and machinery. Regression analysis was again employed in analyzing the relationship of commercial vehicles generated per day to various independent variables such as employment, total floorspace, non-office floorspace, and site area. Four forms of regression relationships were considered: linear ($Y = a + bx$), parabolic ($Y = a + bx + cx^2$), geometric ($Y = ax^b$), and exponential ($Y = ab^x$). Only the linear and parabolic regression forms gave satisfactory results in terms of R^2 and the significance of the regression.

In contrast to previous studies, which determined that the number of employees was the single most important variable in explaining truck trip ends, Leake and Gan found that, depending on the S.I.C. category under consideration, either floor area or site area was the single most significant variable. This dominance of area-type

variables was attributed to the distribution function of the particular industrial types surveyed and their associated requirements for storage and for loading or unloading areas.

A final outcome of the Leake and Gan study was that the five industrial groups generated truck trips at significantly different rates. This again points out the necessity of individual investigation of truck trip rates by detailed land use or Standard Industrial Classification categories.

Maltby (1973)

A more recent study by Maltby has investigated the characteristics of "non-work" traffic to selected manufacturing establishments in Sheffield and Manchester, England. In an attempt to conduct a study of more "rigor" than those previously performed, Maltby pays careful attention to sample selection, samples over a longer period of time, and employs a comparison of regressions approach to suggest similarities in commercial vehicle trip rates both across several different manufacturing groups and between the two study areas. Analysis of variance is employed to select the most explanatory independent variable in the regression analyses.

Results of the research showed that similarities in trip rates over the seven different industrial groups in Sheffield existed for both "service" and "business" trips generated by the establishments. "Goods" trips (those trips made by commercial vehicles over 30 cwt.), however, showed different trip rates for the different industries; a grouping into heavy and light industries, each with a unique rate, was therefore suggested. Evidence of similarities in trip rates for all

three categories of movement was shown across the two study areas although this analysis was performed for only one industrial group.

The analysis of variance to select the single most explanatory variables for the regression analyses indicated that, while employment was most significant for business movements, production floorspace was the best single variable for use with "goods" movements. None of the developed relationships, however, were extremely reliable.

Because of the unreliability of the developed relationships, Maltby concluded that the simple linear regression form is the most complexity which may be achieved in modeling non-work traffic movements. He suggests, in fact, that simple trip rates for various establishment size ranges may be sufficient. Large sample sizes are necessary, however, and the temporal stability of the trip rates should be closely monitored.

Watson (1975, pp. 43-64)

One of the more recent research projects on truck trip generation characteristics at manufacturing establishments has been reported by Watson for twelve light manufacturing and engineering companies in the Evanston-Skokie, Illinois, area. In addition to collecting information on both inbound and outbound truck movements at each firm over a week's period, Watson also collected information on plant employment by type and plant floor area by function. An attempt also was made to collect various financial data, such as total sales, profits, inventory levels, and plant value. Results, unfortunately, were discouraging and none of the financial data could be used in subsequent analyses.

The resulting truck trip models, developed through regression analysis techniques, indicated the following conclusions:

a.) total truck trips may be explained equally well by either total employment or total floorspace;

b.) simple linear regression models are less effective than regression models created by logarithmic transformations of the variables;

c.) stratification of the employment and floorspace variables by type and function does not result in improved models;

d.) the development of separate models for inbound and outbound movements is not extremely fruitful although inbound trips are more closely related to employment variables while outbound trips show a better relationship with floorspace variables.

Keefer and Witheford (Keefer, 1966; Keefer and Witheford, 1969)

Some early treatments of non-industrial truck trip movements have been a part of larger studies conducted by Keefer and Witheford for the National Cooperative Highway Research Program on urban travel patterns to airports, shopping centers, industrial plants, hospitals, universities, office buildings, and capitols. Truck trip movements, however, were largely incidential to other traffic movements at these special generators. No truck trip rates for these facilities were developed, in fact. Instead, the total number of truck trips per 100 or 1,000 automobile trips were reported depending upon the particular generator.

Among the special generators which had significant numbers of truck trips were industrial plants with 3.52 total truck trips per

100 person trips (Keefer, 1966, p. 69) and office buildings with about 8.0 truck trips per 100 automobile driver trips (Keefer and Witheford, 1969, p. 7).

Smith (1969, pp. 65-70)

Another earlier study which reported on truck trip generation for non-industrial land uses is described in Motor Trucks in the Metropolis. Using data from Baton Rouge, Louisiana, this study developed truck trip attraction rates per 1,000 square feet of retail sales area for various groups of convenience commercial establishments. Convenience sales were defined as less costly commercial transactions, drugs and food, for example, as opposed to sales of more durable goods such as general merchandise, apparel, and furnishings. Results of the study are shown in Table 3-7.

TABLE 3-7

TRUCK TRIP ATTRACTION RATES TO COMMERCIAL LAND
BATON ROUGE, LOUISIANA
(1967)

Retail Sales Composition	Trips per 1,000 Retail Square Feet				
	Light Trucks	Medium & Heavy Trucks	Total Trucks	Empty Trucks	Loaded Trucks
All Convenience	8.0	2.6	10.6	3.8	6.8
High Convenience	3.6	1.5	5.1	1.6	3.5
Low Convenience	2.6	0.6	3.2	1.4	1.8

Source: Wilbur Smith and Associates. Motor Trucks in the Metropolis. Under commission from the Automobile Manufacturers Association, New Haven, Ct., 1969, p. 69.

Bates (1970)

As part of a research project for the Canadian Trucking Association, Bates developed truck stop generation rates for selected establishment types in the central area of Toronto, Canada. These rates are shown in Table 3-8. In addition to the rates shown in the table, truck stops at restaurants, averaging about six stops per day, were recorded. Lack of floor area variables for the restaurants precluded trip rate calculations for these facilities.

TABLE 3-8

TRUCK STOP GENERATION RATES
CENTRAL TORONTO
(1970)

Land Use	Average Number of Truck Stops Generated Per 1,000 Square Feet of Floor Area
Manufacturing	0.68
Warehousing	0.53
Office	0.22
Department Store	0.24

Source: Malcolm V. Bates. Goods Movement by Truck in the Central Area of Selected Canadian Cities. Ottawa, Ontario: Canadian Trucking Association, 1970, p. 85.

Meyburg and Stopher (1973, pp. 233-241)

Meyburg and Stopher studied freight vehicle attraction models developed for 23 shopping centers in the Syracuse, Ithaca, and Courtland, New York areas. Results of their research indicated that

regression-type freight vehicle movement models could be developed using total floor area and the total number of employment hours per week as significant independent variables. When separate models were developed based on individual store types within the shopping centers, however, few of the results exhibited any validity or consistency.

Zevin (1974)

As part of a statewide study of the trip generating characteristics of various land uses in Connecticut, Zevin obtained an estimate of the average number of trucks stopping at each of 13 industrial parks in the state. The findings, when combined with the total number of employees and the square feet of gross floor area at each of the sites, resulted in truck trip rates of 2.39 truck trips per 10 employees and 5.43 truck trips per 10,000 square feet of floorspace, respectively.

Saunders (1973, pp. 1-29)

Saunders, in a recent study of truck trip generation, reported on the efforts of the Greater London Council (GLC) to develop a goods vehicle model considering four truck trip types:

a.) light goods-vehicle trips to "industrial" land uses (industry, open space, transportation and utilities, and vacant);

b.) heavy goods-vehicle trips to "industrial" land (as in (a) above);

c.) light goods-vehicle trips to "non-industrial" or "consumer-oriented" land uses (residential, commercial, office, educational and health, and public buildings);

d.) heavy goods-vehicle trips to "non-industrial" land uses

(as in (c) above).

The researchers found several areas of weakness in the above models including a linear approach to what possibly might be non-linear behavior and low levels of explanatory power.

Holder, Christiansen, and Smith (1974, pp. 4-14)

The final example of non-industrial truck trip generation rates was reported by Holder, Christiansen, and Smith for estimating the magnitude of truck activity in the Dallas, Texas central business district. The rates were given in terms of daily truck stops per 10,000 square feet of floor area for each of several primarily CBD-related functions. The rates are shown in Table 3-9.

TABLE 3-9

DOWNTOWN TRUCK STOP RATES
DALLAS, TEXAS

Land Use	Daily Truck Stops Generated Per 10,000 Square Feet of Floor Area
Office	2.1
Retail[a]	7.0
Department Stores	2.4
Hotels	1.0
Parking	0.0

Source: R. W. Holder, Dennis L. Christiansen, and Roy A. Smith. "Delivery of Goods and Services in Downtown Dallas - the Problem and Alternative Solutions." Texas Engineering Experiment Station Technical Bulletin. No. 74-3. College Station, Texas: TEES Publications, July, 1974, p. 5.

[a]Average of all retail uses.

Summary

This chapter has attempted to summarize the state of the art of truck trip generation at the establishment level. The use of the business establishment as the basic unit of analysis in truck trip generation has been compared with the more traditional approach which uses the individual vehicle as the analysis unit. Advantages of the establishment method have been listed and the applications of establishment level results have been detailed. These applications relate both to local impact analyses and the development of off-street loading standards.

The final portion of the chapter has discussed in detail the previous research on establishment-level truck trip generation analysis. Both industrial and non-industrial truck trip generation studies have been reported although a substantial portion of research has been on the industrial sector.

The models of truck trip generation at the establishment level, both industrial and non-industrial, are usually simple linear regressions with either total floorspace or total employment as the independent variable. In some cases logarithmic transformations of the variables improve model performance. Caution must be exercised in the use of models containing transformed variables, however, as the transformations, particularly those made on the dependent variable, may lead to violations of the least squares assumptions on which the regression analysis procedure is based (Draper and Smith, 1966, p. 134). In addition, interpretation of models with variable transformations is often difficult and forecasting may also be a problem.

In any case, the need for variable transformations may indicate the presence of a non-linear relationship and this possibility has prompted many researchers to propose including establishment size in the model formulation. This consideration is most easily accomplished by developing truck trip generation rates for various size establishment groups.

CHAPTER 4

IMPROVING TRUCK TRIP GENERATION TECHNIQUES THROUGH TRIP END STRATIFICATION

Most existing urban truck travel demand forecasting techniques stratify truck trips into only two categories for modeling purposes--trips made by light trucks (those trucks with only two axles and four tires and usually weighing less than 10,000 pounds gross) and trips made by heavy trucks (those trucks with more than four tires and a gross vehicle weight of more than 10,000 pounds). Additional stratifications are sometimes made, for example, by subdividing the "heavy" truck category into "medium" trucks (those having no more than two axles and a gross weight of 10,000 to 20,000 pounds) and "heavy" trucks (those having a gross weight of more than 20,000 pounds) (Smith, 1969, p. 28). For the most part, however, the two category breakdown by light and heavy vehicles is the one most frequently made.

The rationale behind the stratification by light and heavy vehicle types is, of course, that the trip-making characteristics of the two types are quite different and they should thus be analyzed independently. Trip length characteristics of the two truck types do, in fact, show considerable differences; this is indicated by the trip length distribution and friction factor values for the two truck types as shown previously in Figures 2-1 and 2-2, respectively (pp. 21 and 23).

The purpose of this section of the research is to determine if additional stratification of truck trips aids in improving the reliability of truck trip forecasts. Several additional stratifications are considered:

a) additional stratifications by vehicle type (for example, panel and pickup trucks, other two axle trucks, three axle single unit trucks, and all combination units);

b) stratification by trip purpose; and

c) stratification by land use at destination.

Testing for truck trip generation modeling improvements through the additional truck trip stratifications involves the analysis of both external and internal truck survey trip records from the origin-destination study files in each of several case study cities. Zonal-level truck trip ends for each of the proposed trip stratifications by the various parameters listed above are sorted and accumulated and regression equations are developed for the stratified data. Comparisons with the original unstratified regression equations (in terms of both the statistical adequacy of the regressions and the significant independent variables in the relationships) are made to reveal any improvements resulting from the stratifications.

The chapter begins by considering the effect of truck trip end stratification in multiple regression analysis by the three parameters listed above--truck type, trip purpose, and land use at destination. A proposed stratification of truck trips is then presented and the applications of the stratified regression relationships to truck travel demand forecasting are discussed.

The Development of Stratified Zonal Trip Generation Relationships

Procedure for Developing Stratified Regression Equations

The procedure used in the development of the stratified multiple regression equations by various classes of truck type, trip purpose, and destination land use involved obtaining the coded truck trip records for both the internal truck survey and external cordon survey from each of the selected case study cities. From the raw truck trip data records, a series of trip tables (matrices containing the inter-zonal truck traffic movements) for each class of the stratified survey variable were constructed using the standard TRPTAB program in the urban transportation planning computer package (FHWA Computer Programs for Urban Transportation Planning, 1974, pp. 557-574). Separate computer runs were made for stratifications by vehicle type, trip purpose, and destination land use as well as for both the internal and external cordon truck surveys. Output from the TRPTAB program, in terms of production and attraction truck trip end summaries by traffic zone, was punched on cards for use in the regression analyses.

The regression program employed for the development of the stratified truck trip generation models was a modification of the BMDO2R stepwise multiple regression program developed by the University of California (Dixon, 1973, pp. 305-330). The modification, entitled BPRO2R, has features which make it compatible with the other programs in the Federal Highway Administration battery (FHWA Computer Programs for Urban Transportation Planning, 1974, pp. 60-70).

Use of the BPRC2R program was made in the development of stepwise multiple regression equations in each case study city for both the total unstratified truck trips and each of the classes in the specific trip stratification category. Separate equations were developed for productions and attractions (origins and destinations) and for both the internal and external cordon truck surveys. The results, for each stratification category in the selected cities for which data were available, are described in subsequent sections.

Stratification by Vehicle Type

The stratification of truck trips by vehicle size has been shown to be a logical approach to truck trip generation analysis due to the unique trip-making characteristics of various type truck vehicles. Truck size is also important, however, in terms of facility design (for both geometric and pavement considerations), environmental impact analyses, fuel and energy consumption studies, and highway revenue forecasts from estimates of truck vehicle-miles of travel.

The traditional stratification of truck trips into those made by light and heavy vehicles, however, when used to develop multiple regression relationships to forecast truck trip ends, has generally yielded unsatisfactory results. Correlations usually have been low, standard errors have been quite high, and, in general, the equations have tended to be so complex and unwieldy as to make forecasting extremely difficult.

It was felt, therefore, that the investigation of additional truck trip stratifications based on vehicle size might result in

improved and simplified truck trip generation models. Accordingly, truck trip origin-destination data were obtained from three case study cities--Gastonia, North Carolina; Flint, Michigan; and Saginaw, Michigan--and stratified multiple regression relationships were developed by truck type and compared to the overall unstratified regression equations in each city. The results of the stratifications by vehicle type for each of the three cities are summarized below.

Gastonia. Truck trip records from both the internal truck survey and the external cordon survey were available from a 1969 origin-destination survey of Gastonia, a city with a study area of approximately 109,000 population in southern North Carolina. The average daily number of truck trips between the study area's 219 traffic zones, including those trips with only one trip end in a zone (external-internal or internal-external trips) was approximately 50,000 in 1969. An additional 7,500 truck trips, over half of them by tractor-trailer units, passed through, but did not stop in, the study area (through trips).

Ten demographic and socioeconomic independent variables were available on a zonal basis for developing regression relationships for predicting various truck trip end totals in Gastonia. These variables were:

a.) industrial employment,

b.) retail employment,

c.) highway employment (employment in establishments which serve primarily highway users, such as motel, restaurant, and service station employees),

d.) office employment,

e.) service employment,

f.) total employment,

g.) low income dwelling units (less than $8,000/year),

h.) medium income dwelling units ($8,000 to $15,000/year), and

i.) high income dwelling units (over $15,000/year).

j.) total dwelling units

Two separate trip stratifications by vehicle type were developed. The first stratification broke down the total truck population into panel-pickup trucks versus other-than-panel-pickup trucks. The second stratification considered all single-rear-tire trucks separately from all other-than-single-rear-tire trucks. Results of the two vehicle type stratifications for internal and external truck movements are given in Tables 4-1 and 4-2, respectively, which show for each category the developed multiple regression equation with two independent variables (the addition of more than two independent variables usually led to problems of colinearity; in addition, added variables were often not significant), the overall F testing the significance of the regression, the coefficient of multiple determination, the standard error of the estimate as a proportion of the mean, the mean value of the dependent variable, and the simple correlation coefficients between each set of variables in the equation.

It can be seen from Table 4-1 that the stratifications by panel-pickup versus other-than-panel-pickup and single-rear-tire-trucks versus other-than-single-rear-tire-trucks did not improve the truck trip generation results. In fact, both stratifications actually increased the standard error of the estimate as a proportion of the mean

TABLE 4-1

GASTONIA INTERNAL TRUCK TRIP DESTINATIONS BY TRUCK TYPE

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
TOTAL Truck Destinations = 77.7 + 1.54 (Retail Employment) + 0.54 (Total Low Income Dwelling Units)	59.6	0.3555	1.0163	159.75	$r_{12} = 0.536$ $r_{13} = 0.269$ $r_{23} = 0.016$
Panel-Pickup Destinations = 41.6 + 2.35 (Highway Employment) + 0.10 (Total Employment)	61.3	0.3622	1.0309	87.84	$r_{12} = 0.506$ $r_{13} = 0.468$ $r_{23} = 0.313$
Other than Panel-Pickup Destinations = 34.6 + 0.76 (Retail Employment) + 0.23 (Total Low Income Dwelling Units)	52.1	0.3252	1.1619	71.92	$r_{12} = 0.527$ $r_{13} = 0.227$ $r_{23} = 0.016$

TABLE 4-1 (continued)

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
Single Rear Tire Truck Destinations = 47.6 + 1.14 (Retail Employment) + 0.33 (All Dwelling Units)	55.2	0.3384	1.0286	123.95	$r_{12} = 0.504$ $r_{13} = 0.283$ $r_{23} = -0.016$
Other than Single Rear Tire Truck Destinations = 22.0 + 0.30 (Retail Employment) + 0.71 (Highway Employment)	44.6	0.2924	1.3644	35.80	$r_{12} = 0.508$ $r_{13} = 0.459$ $r_{23} = 0.618$

[a] r_{12} = Correlation between dependent variable and 1st independent variable; r_{13} = Correlation between dependent variable and 2nd independent variable; r_{23} = Correlation between independent variables.

TABLE 4-2

GASTONIA EXTERNAL TRUCK TRIP DESTINATIONS BY TRUCK TYPE

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
TOTAL Truck Destinations = 17.4 + 0.20 (Retail Employment) + 0.03 (Total Employment)	91.7	0.4592	0.7960	29.16	$r_{12} = 0.601$ $r_{13} = 0.558$ $r_{23} = 0.468$
Panel-Pickup Destinations = 12.21 + 0.14 (Retail Employment) + 0.02 (Total Employment)	91.1	0.4577	0.8003	20.31	$r_{12} = 0.609$ $r_{13} = 0.546$ $r_{23} = 0.468$
Other than Panel-Pickup Destinations = 4.28 + 0.19 (Highway Employment) + 0.01 (Total Employment)	47.7	0.3066	1.1224	8.86	$r_{12} = 0.428$ $r_{13} = 0.468$ $r_{23} = 0.313$

TABLE 4-2 (continued)

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
Single Rear Tire Truck Destinations = 12.57 + 0.15 (Retail Employment) + 0.02 (Total Employment)	95.5	0.4693	0.7946	20.97	$r_{12} = 0.622$ $r_{13} = 0.545$ $r_{23} = 0.468$
Other than Single Rear Tire Truck Destinations = 4.05 + 0.16 (Highway Employment) + 0.01 (Total Employment)	42.0	0.2802	1.1649	8.19	$r_{12} = 0.394$ $r_{13} = 0.459$ $r_{23} = 0.313$

[a] r_{12} = Correlation between dependent variable and 1st independent variable; r_{13} = Correlation between dependent variable and 2nd independent variable; r_{23} = Correlation between independent variables.

and only one stratified equation, for panel-pickup destinations, had even the slightest increase in the value of R^2. The value of the overall F, significant at the 0.01 level for all equations, was increased in only one of the stratified equations, again the panel-pickup destinations equation.

Only a total of five independent variables appear in the five equations indicating little underlying difference between the stratified trip types. Retail employment, for example, was the most significant independent variable in four of the equations. In general, the panel-pickup and single rear tire equations were more acceptable than the equations for the larger truck vehicles. The equation for other-than-single-rear-tire-trucks, in fact, may be difficult to interpret because of the existence of colinear variables (the correlation between the two independent variables is higher than the correlation of either of them with the dependent variable). The net effect of the stratification by truck type for internal trucks was that the regularity of small truck vehicles was much more apparent than that of the larger, dual-tired single unit and combination vehicles. Modeling of these heavier vehicle movements would thus seem much more risky.

Similar conclusions may be reached regarding the regression relationships for the external truck movements summarized in Table 4-2. Once again, significant regressions were achieved in all cases but little improvement resulted from the stratifications. The value of R^2 increased over that of the unstratified equation in only one instance and standard errors as a proportion of the mean were actually increased in three of the four stratified equations. Only three

independent variables were represented in the five equations with either retail or highway employment the most significant variable and total employment the second variable to enter the equations in all cases.

An additional constraint placed on the stratification of the external truck movements was the fact that there were comparatively few destination trip ends for the larger truck vehicles. As a result, the regression relationships for these movements take on an even more questionable nature.

Flint. Truck origin-destination data were also available from the 1966 origin-destination study in Flint, Michigan. The Flint-Genesee County study area of approximately 660 square miles with a population of over 447,000 was divided into 315 internal traffic analysis zones. Total truck travel in the area at the time of the origin-destination survey was approximately 107,000 truck trips per day, both internal and external (Flint 1966 Origin-Destination Study Summary Report, 1972, pp. 7, 15).

Ten zonal-level independent variables were available for use in developing the stratified regression relationships for Flint. These variables were: manufacturing employment, commercial employment, service employment, professional employment, other employment, total employment, total population, total dwelling units, total automobiles and resident labor force.

In addition to the general stratifications used in the Gastonia data, the coding of the Flint truck trips, both internal and external, enabled an additional stratification of single unit trucks versus

combination (tractor-trailer) units to be made. Thus, a total of three stratifications were considered--single unit, single tire vehicles versus other than single unit, single tire vehicles; single axle vehicles versus other than single axle vehicles; and single unit trucks versus combination (tractor-trailer) units.

Tables 4-3 and 4-4 summarize the Flint stratifications by truck type for destination trip ends and compare them to the unstratified equations for internal trips and external trips, respectively. An examination of Table 4-3 shows that the three straight truck equations (single unit-single rear tire, single axle, and single unit trucks) all contain the same independent variables (total employment and total autos) as the total truck equation. In addition, the single unit equations all have approximately the same statistical adequacy (in terms of R^2 and percent standard error) as the overall equation and there seem to be no confounding effects due to colinearity among the variables.

Where all the Flint stratifications by vehicle type failed, however, was in their attempts to model the heavier truck trip ends. The equations for all three of these categories (other than single unit-single tire, other than single axle, and other than single unit vehicles) are quite weak with considerably lower values of R^2, high standard errors of the estimate and quite low, although still significant, overall F values. The independent variables in the "other than" categories, moreover, while significant from a statistical standpoint, sometimes do not seem logically correct. While the use of commercial employment in the other-than-single-unit-single-tire equation as an important predictor of "heavy" truck trip ends may make sense, for

TABLE 4-3

FLINT INTERNAL TRUCK TRIP DESTINATIONS BY TRUCK TYPE

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
TOTAL Truck Destinations = 98.4 + 0.13 (Total Employment) + 0.34 (Total Autos)	145.8	0.4831	0.7450	337.54	$r_{12} = 0.567$ $r_{13} = 0.339$ $r_{23} = -0.107$
Single Unit, Single Tire Destinations = 57.0 + 0.10 (Total Employment) + 0.29 (Total Autos)	159.0	0.5048	0.7468	256.77	$r_{12} = 0.556$ $r_{13} = 0.381$ $r_{23} = -0.107$
Other than Single Unit, Single Tire Destinations = 53.6 + 0.21 (Commercial Employment) + 0.03 (Total Employment)	63.0	0.2876	1.0960	80.77	$r_{12} = 0.352$ $r_{13} = 0.448$ $r_{23} = 0.133$
Single Axle Destinations = 82.8 + 0.11 (Total Employment) + 0.32 (Total Autos)	143.9	0.4799	0.7202	300.25	$r_{12} = 0.533$ $r_{13} = 0.382$ $r_{23} = -0.107$
Other than Single Axle Destinations = 14.5 + 0.02 (Total Employment) + 0.03 (Total Dwelling Units)	54.4	0.2584	1.7939	37.29	$r_{12} = 0.495$ $r_{13} = 0.077$ $r_{23} = -0.080$

TABLE 4-3 (continued)

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
Single Unit Destinations = 88.1 + 0.12 (Total Employment) + 0.33 (Total Autos)	141.0	0.4747	0.7286	315.45	$r_{12} = 0.534$ $r_{13} = 0.376$ $r_{23} = -0.107$
Other than Single Unit Destinations = 15.1 - 0.03 (Professional Employment) + 0.02 (Total Employment)	44.2	0.2207	2.5211	22.09	$r_{12} = -0.042$ $r_{13} = 0.460$ $r_{23} = 0.109$

[a] r_{12} = Correlation between dependent variable and 1st independent variable; r_{13} = Correlation between dependent variable and 2nd independent variable; r_{23} = Correlation between independent variables.

TABLE 4-4

FLINT EXTERNAL TRUCK TRIP DESTINATIONS BY TRUCK TYPE

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
TOTAL Truck Destinations = 3.85 + 0.02 (Total Employment) + 0.02 (Total Autos)	147.3	0.4857	1.4133	22.82	$r_{12} = 0.675$ $r_{13} = 0.099$ $r_{23} = -0.107$
Single Unit, Single Tire Destinations = 1.87 + 0.01 (Total Employment) + 0.01 (Total Autos)	92.3	0.3718	1.4687	12.27	$r_{12} = 0.567$ $r_{13} = 0.163$ $r_{23} = -0.107$
Other than Single Unit, Single Tire Destinations = 4.60 + 0.03 (Other Employment) + 0.01 (Total Employment)	130.9	0.4562	1.8462	10.55	$r_{12} = 0.363$ $r_{13} = 0.662$ $r_{23} = 0.359$
Single Axle Destinations = 3.14 + 0.01 (Total Employment) + 0.02 (Total Autos)	69.6	0.3084	1.4327	15.92	$r_{12} = 0.497$ $r_{13} = 0.194$ $r_{23} = -0.107$
Other than Single Axle Destinations = 1.39 + 0.02 (Other Employment) + 0.01 (Total Employment)	162.9	0.5109	2.4011	6.90	$r_{12} = 0.354$ $r_{13} = 0.707$ $r_{23} = 0.359$

TABLE 4-4 (continued)

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
Single Unit Destinations = 2.67 + 0.01 (Total Employment) + 0.02 (Total Autos)	70.5	0.3113	1.4533	16.68	$r_{12} = 0.494$ $r_{13} = 0.205$ $r_{23} = -0.107$
Other than Single Unit Destinations = 2.08 - 0.01 (Professional Employment) + 0.01 (Total Employment)	175.6	0.5295	2.4732	6.14	$r_{12} = -0.027$ $r_{13} = 0.720$ $r_{23} = 0.109$

[a] r_{12} = Correlation between dependent variable and 1st independent variable; r_{13} = correlation between dependent variable and 2nd independent variable; r_{23} = correlation between independent variables.

example, it is difficult to see the relationship of total dwelling units to "heavy" truck trip ends.

Finally, there is some problem with colinear variables in the equations for the heavier vehicles where, for example, the correlation between total employment and total dwelling units in the other than single axle equation is greater than the correlation between other than single axle destinations and total dwelling units. These confounding effects may be partly responsible for such peculiarities as the inverse relationship between combination unit destinations and professional employment.

Problems similar to those just mentioned for the stratification of internal truck trips in Flint also exist in the stratification of the Flint external cordon trips. As Table 4-4 shows, however, the single unit categories are now the ones in which little reliability was achieved. The stratified external equations also were based on low mean values and the problem of colinear variables again arises in several of the equations used to predict heavier truck trip ends.

In summary, it can be said that no improvement was observed for either the internal or external truck trip destination models in Flint when stratified by various combinations of vehicle type. Although one portion of the stratification always yielded results comparable to the overall, unstratified equation, the complementary equation was always much poorer, with the overall result of making the entire stratification no better, and oftentimes worse, than the original unstratified equation.

Saginaw. The final urban area in which stratifications by vehicle type were performed was Saginaw, Michigan. The Saginaw origin-destination survey, conducted in 1965, took place in a study area of 211 square miles with a population of over 160,000. An average weekday total of over 48,000 truck trips were made within and between the area's 256 traffic zones at the time the study was conducted (Factual Data Report, 1969, p. 2).

Independent zonal socioeconomic and demographic variables available for use in the truck trip generation equations in Saginaw were: total population, total number of dwelling units, total automobiles, resident labor force, manufacturing employment, service employment, transportation and communication employment, commercial employment, other employment, and total employment.

Stratifications identical to those used in Flint were employed in the analysis of the Saginaw data. Thus, three stratifications were made and compared to the overall equation for truck trip destinations. These stratifications were: single unit-single tire vehicle destinations versus other than single unit-single tire vehicle destinations, single axle vehicle destinations versus other than single axle vehicle destinations, and single unit vehicle destinations versus other than single unit vehicle destinations.

Results of the vehicle type stratification for internal truck trips in Saginaw are shown in Table 4-5. It can be seen from the table that, once again, although significant regressions were achieved, no improvement in the equations resulted from the stratifications. The minimal increases in the coefficient of multiple determination

TABLE 4-5

SAGINAW INTERNAL TRUCK TRIP DESTINATIONS BY TRUCK TYPE

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
TOTAL Truck Destinations = 23.6 + 0.43 (Total Dwelling Units) + 0.12 (Total Employment)	191.7	0.6025	0.8188	137.00	$r_{12} = 0.544$ $r_{13} = 0.556$ $r_{23} = 0.005$
Single Unit, Single Tire Destinations = 14.6 + 0.31 (Total Dwelling Units) + 0.10 (Total Employment)	220.6	0.6356	0.7991	98.66	$r_{12} = 0.539$ $r_{13} = 0.591$ $r_{23} = 0.005$
Other than Single Unit, Single Tire Destinations = 9.00 + 0.12 (Total Dwelling Units) + 0.03 (Total Employment)	78.2	0.3820	1.1355	38.34	$r_{12} = 0.478$ $r_{13} = 0.394$ $r_{23} = 0.005$
Single Axle Destinations = 20.8 + 0.30 (Resident Labor Force) + 0.12 (Total Employment)	200.2	0.6128	0.8121	127.60	$r_{12} = 0.562$ $r_{13} = 0.553$ $r_{23} = 0.013$
Other than Single Axle Destinations = 6.42 + 0.07 (Transportation and Communication Employment) + 0.01 (Total Employment)	22.0	0.1480	2.0275	9.40	$r_{12} = 0.226$ $r_{13} = 0.335$ $r_{23} = 0.110$

TABLE 4-5 (continued)

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
Single Unit Destinations = 23.2 + 0.30 (Resident Labor Force) + 0.12 (Total Employment)	184.7	0.5935	0.8338	131.23	$r_{12} = 0.549$ $r_{13} = 0.547$ $r_{23} = 0.013$
Other than Single Unit Destinations = 1.94 + 0.01 (Total Dwelling Units) + 0.01 (Total Employment)	24.6	0.1631	2.2340	5.76	$r_{12} = 0.186$ $r_{13} = 0.360$ $r_{23} = 0.005$

[a] r_{12} = Correlation between dependent variable and 1st independent variable; r_{13} = correlation between dependent variable and 2nd independent variable; r_{23} = correlation between independent variables.

and the slightly lower values of the standard error of the estimate as a proportion of the mean for the single unit categories in the first two stratifications are more than offset by complementary inverse changes in these values for the corresponding "other than" equations.

In only three of the six stratified equations do independent variables other than those in the unstratified equation enter. Resident labor force is significant in the single axle and single unit equations. This variable, however, is a strong surrogate for total dwelling units, as shown by their correlation coefficient of 0.980. Thus, the only unique variable in any of the stratifications is transportation and communication employment in the other than single axle equation.

Similar conclusions may be reached regarding the stratification of external truck trip destinations, shown in Table 4-6. In this case, none of the stratified equations contains independent variables other than those appearing in the original unstratified equation. Values of R^2 and percent standard error, moreover, did not show overall improvement due to the stratifications even though the individual single unit equations were improved somewhat. In general, however, the stratifications by vehicle type once again were no better than the original unstratified equation.

Stratification by Trip Purpose

Stratification of vehicle trips by trip purpose has long been a practice in the modeling of passenger movements. Although the trip purpose stratifications employed in passenger travel demand

TABLE 4-6

SAGINAW EXTERNAL TRUCK TRIP DESTINATIONS BY TRUCK TYPE

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
TOTAL Truck Destinations = 9.27 + 0.17 (Transportation and Communication Employment) + 0.04 (Total Employment)	141.2	0.5275	1.4117	20.33	$r_{12} = 0.291$ $r_{13} = 0.694$ $r_{23} = 0.110$
Single Unit, Single Tire Destinations = 4.34 + 0.06 (Transportation and Communication Employment) + 0.02 (Total Employment)	226.2	0.6413	1.2445	10.58	$r_{12} = 0.243$ $r_{13} = 0.785$ $r_{23} = 0.110$
Other than Single Unit, Single Tire Destinations = 4.93 + 0.10 (Transportation and Communication Employment) + 0.01 (Total Employment)	59.6	0.3202	1.9328	9.74	$r_{12} = 0.297$ $r_{13} = 0.512$ $r_{23} = 0.110$
Single Axle Destinations = 7.03 + 0.11 (Transportation and Communication Employment) + 0.02 (Total Employment)	178.6	0.5854	1.2112	14.71	$r_{12} = 0.290$ $r_{13} = 0.736$ $r_{23} = 0.110$
Other than Single Axle Destinations = 2.24 + 0.06 (Transportation and Communication Employment) + 0.01 (Total Employment)	54.2	0.2999	2.4929	5.61	$r_{12} = 0.245$ $r_{13} = 0.514$ $r_{23} = 0.110$

TABLE 4-6 (continued)

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
Single Unit Destinations = 7.79 + 0.12 (Transportation and Communication Employment) + 0.03 (Total Employment)	166.8	0.5688	1.2192	15.86	$r_{12} = 0.292$ $r_{13} = 0.723$ $r_{23} = 0.110$
Other than Single Unit Destinations = 1.48 + 0.05 (Transportation and Communication Employment) + 0.01 (Total Employment)	54.2	0.2930	2.8232	4.46	$r_{12} = 0.235$ $r_{13} = 0.511$ $r_{23} = 0.110$

[a] r_{12} = Correlation between dependent variable and 1st independent variable; r_{13} = correlation between dependent variable and 2nd independent variable; r_{23} = correlation between independent variables.

forecasting are dictated primarily by the trip distribution model requirements (Guidelines for Trip Generation Analysis, 1976, p. 43), decisions must be made at the trip generation stage as to the number and type of trip purpose stratifications to employ.

Considerations in the stratification of passenger trips by trip purpose include not only the number of trips in each category but also the trip length distributions of each trip purpose and the ability to forecast future trips in each category separately (Guidelines for Trip Generation Analysis, 1967, p. 43). Thus, the total number of trip purposes may range from eight or more in large urban area studies to as few as three (home-based work, home-based other, and non-home-based) in the smaller urban areas.

Transferring the above reasoning to an analysis of goods-movement vehicle trips indicated that some stratification of truck vehicle trips by trip purpose should be investigated. Although a number of stratifications by trip purpose are theoretically possible, it is necessary to limit the total number of purposes both because of the comparatively small number of truck vehicle movements taking place and also because of limitations on the number of trip purpose categories traditionally collected in an origin-destination survey.

Truck trip data available for this research were thus grouped into two general trip purpose categories--"goods"-related trips (those trips which had as their primary purpose the pickup or delivery of goods) and "service"-related trips (those truck trips where the vehicle was used in connection with some type of service function). Data from two of the case study cities used in the trip type analysis--

Gastonia, North Carolina and Flint, Michigan were also available for use in stratification by trip purpose. Only the internal truck survey in these cities had coded truck trip purpose; results for external truck trips are thus not available.

The results of the trip purpose stratification for each of the two case study cities are discussed below.

Gastonia. Two stratification categories by trip purpose for the internal truck trip destinations in Gastonia were created. "Goods" truck destinations consisted of those truck trips with trip purpose codings of pickup goods, deliver goods, pickup and deliver goods, and garage address; this category was thus primarily "goods movement" related. The second general trip purpose category was labeled "service" truck destinations and included the trip purposes of service call, vehicle repair, and personal business; it was thus more "service" related.

A comparison of the trip purpose stratification for Gastonia with the overall unstratified equation is given in Table 4-7. Goods truck destinations, which made up about two-thirds of the total truck destinations, are seen to be best predicted by the same independent variables present in the overall model. The coefficient of multiple determination for the "goods" model is somewhat higher than that of the overall equation; the standard error as a proportion of the mean, however, is higher for the stratified goods model.

The significant independent variables in the "service" model are highway employment, defined as employees in establishments which serve primarily highway users, such as motel, restaurant, and service station

TABLE 4-7

GASTONIA INTERNAL TRUCK TRIP DESTINATIONS BY TRIP PURPOSE

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
TOTAL Truck Destinations = 77.7 + 1.54 (Retail Employment) + 0.54 (Total Low Income Dwelling Units)	59.6	0.3555	1.0163	159.75	$r_{12} = 0.536$ $r_{13} = 0.269$ $r_{23} = 0.016$
"Goods" Trucks Destinations = 50.1 + 1.10 (Retail Employment) + 0.33 (Total Low Income Dwelling Units)	64.1	0.3726	1.0470	104.07	$r_{12} = 0.564$ $r_{13} = 0.242$ $r_{23} = 0.016$
"Service" Trucks Destinations = 27.8 + 1.15 (Highway Employment) + 0.07 (Total Employment)	39.8	0.2694	1.1904	55.68	$r_{12} = 0.395$ $r_{13} = 0.443$ $r_{23} = 0.313$

[a] r_{12} = Correlation between dependent variable and 1st independent variable; r_{13} = correlation between dependent variable and 2nd independent variable; r_{23} = correlation between independent variables.

employees, and total employment; neither of these variables appears in either the overall or the goods-related equation. The R^2 value for the service category, however, is quite low, the standard error as a proportion of the mean somewhat higher than the other two equations, and the overall F value, though still significant, considerably lower than either the total or "goods" model. The stratification by trip purpose may be of some value, nevertheless, since it shows the relationship of "goods"-related trips to measures of retail employment and the importance of "service"-type functions, such as those related to highway service stations, as a predictor of "service"-related truck trips.

Flint. The internal truck trips in Flint were similarly grouped into two general trip purpose categories. The "goods" movement category included the trip purpose codes of pickup goods, deliver goods, pickup and deliver goods, and to base of operations. The "service" category included trips with coded trip purposes of to and from work, shopping, personal business, service and other work connected, and vacation.

Results of the stratification by trip purpose for the internal Flint truck trips are shown in Table 4-8. "Goods" truck destinations are seen to be most highly related to commercial employment while "service"-related destinations are most highly correlated with values of total employment and total autos, the same variables appearing in the total truck equation.

Neither stratified trip purpose category, however, shows a significant improvement over the original total truck destination equation. The service equation does show a somewhat higher value of R^2 and a higher

TABLE 4-8

FLINT INTERNAL TRUCK TRIP DESTINATIONS BY TRIP PURPOSE

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
TOTAL Truck Destinations = 98.1 + 0.14 (Total Employment) + 0.34 (Total Autos)	151.2	0.4922	0.7430	337.80	$r_{12} = 0.568$ $r_{13} = 0.339$ $r_{23} = -0.107$
"Goods" Trucks Destinations = 61.8 + 0.29 (Commercial Employment) + 0.12 (Total Dwelling Units)	46.3	0.2290	0.9313	129.90	$r_{12} = 0.392$ $r_{13} = 0.367$ $r_{23} = 0.260$
"Service" Trucks Destinations = 42.3 + 0.11 (Total Employment) + 0.22 (Total Autos)	198.2	0.5596	0.7950	207.90	$r_{12} = 0.652$ $r_{13} = 0.296$ $r_{23} = -0.107$

[a] r_{12} = Correlation between dependent variable and 1st independent variable; r_{13} = correlation between dependent variable and 2nd independent variable; r_{23} = correlation between independent variables.

overall F value but at the expense of a correspondingly higher value of the standard error as a proportion of the mean.

Stratification by Land Use at Destination

Detailed stratifications of urban goods movements have recently been proposed which relate to the land use classification at the destination end of a goods movement trip. Fresko, Shunk, and Spielberg, for example, propose a classification consisting of location-oriented goods trips which serve the basic employment facilities in an urban region versus resident-oriented goods movements which serve the needs of the resident population in the area (1972, p. 8). Similarly, Saunders categorizes goods vehicle movements as those attracted to either "industrial" land uses (industry, open space, transportation and utilities and vacant) or "non-industrial" or "consumer-oriented" land uses (commercial, public buildings, residential, and services) (1973, p. 3). Finally, Hutchinson proposes grouping all goods movements into two distinct classes--inter-industry and household-based (1974, pp. 2-3).

As a final truck trip end stratification category, then, internal truck trip records from three case study cities--Flint, Michigan; Saginaw, Michigan; and Columbus, Ohio--were stratified into two categories according to the land use at the destination trip end. The categories were industry-oriented truck trips and consumer-oriented truck trips. Results for each of the case study cities are discussed below.

Flint. The total internal truck trip destinations for Flint were grouped into "industrial" or "consumer" trips according to the land use at the trip destination. Industrial trips consisted of those trips which had destination land use codes of manufacturing; transportation, communication, and utilities; wholesale trade; resource production and extraction; and undeveloped land and water areas. Consumer-oriented land uses included land use types residential; retail trade; services; and cultural, recreational, and entertainment.

Results of the regression analyses for the truck data stratified by land use at destination are given in Table 4-9. The stratification shows that industrial type truck destinations are best predicted by manufacturing and other employment variables. Consumer-oriented truck trip destinations, on the other hand, are most significantly related to what might be considered consumer-related variables, that is measures of commercial employment and total dwelling units. Both stratified equations are quite different from the overall equation, which predicts total truck destinations from a combination of industrial-related (total employment) and consumer-related (total autos) variables.

In addition to the logical structure of the truck destination equations stratified by land use at destination, the statistical strength of the separate equations seems improved over that of the unstratified total truck equation. The values of the overall F, for example, show that the industry-oriented truck destination equation is significant at a much higher level of confidence than either of the other equations. The consumer-oriented equation, on the other

TABLE 4-9

FLINT INTERNAL TRUCK TRIP DESTINATIONS BY LAND USE AT DESTINATION

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
TOTAL Truck Destinations = 98.2 + 0.14 (Total Employment) + 0.34 (Total Autos)	146.4	0.4841	0.7450	337.86	$r_{12} = 0.568$ $r_{13} = 0.339$ $r_{23} = -0.107$
"Industry"-Oriented Truck Destinations = 37.6 + 0.20 (Other Employment) + 0.13 (Manufacturing Employment)	420.1	0.7292	1.5410	82.48	$r_{12} = 0.269$ $r_{13} = 0.847$ $r_{23} = 0.196$
"Consumer"-Oriented Truck Destinations = 73.3 + 0.59 (Commercial Employment) + 0.36 (Total Dwelling Units)	140.8	0.4745	0.6723	255.38	$r_{12} = 0.505$ $r_{13} = 0.584$ $r_{23} = 0.260$

[a] r_{12} = Correlation between dependent variable and 1st independent variable; r_{13} = Correlation between dependent variable and 2nd independent variable; r_{23} = Correlation between independent variables.

hand, has a lower F value than the overall equation, and hence cannot be used with as much confidence. The two values are so close, however, (146 versus 141) and the industrial-oriented F value is so high, that there can be little doubt that the stratification by land use at destination has, for the Flint data, resulted in some improvements over the traditional unstratified equation. All of the criteria for determining "improvements" have not been met, however, as the value of R^2 for the "consumer" equation is somewhat lower than that of the overall equation and the standard error as a proportion of the mean for the industrial equation is quite a bit larger than that of the unstratified equation.

Saginaw. Internal truck destinations in Saginaw were also grouped into industrial or consumer-related trip categories depending on the trip's destination land use. The industrial category contained manufacturing, non-manufacturing industry, commercial-wholesale, and other open space land uses. The consumer-related category consisted of residential, commercial-retail, services, public and quasi-public buildings, and public and quasi-public open space land uses.

Results of the destination land use stratification for Saginaw are given in Table 4-10 along with the overall truck equation. It can be readily seen that this stratification has also resulted in some improvements over the overall equation both in terms of the logical placement of the independent variables and the statistical strength of the stratified equations.

Industrial truck trips are strongly related to total employment (a large majority of which is industrial employment) and transportation

TABLE 4-10

SAGINAW INTERNAL TRUCK TRIP DESTINATIONS BY LAND USE AT DESTINATION

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
TOTAL Truck Destinations = 23.6 + 0.43 (Total Dwelling Units) + 0.12 (Total Employment)	192.1	0.6029	0.8183	136.95	$r_{12} = 0.544$ $r_{13} = 0.557$ $r_{23} = 0.005$
"Industry"-Oriented Truck Destinations = 6.12 + 0.36 (Transportation and Communication Employment) + 0.09 (Total Employment)	223.0	0.6380	1.7209	34.23	$r_{12} = 0.277$ $r_{13} = 0.775$ $r_{23} = 0.110$
"Consumer"-Oriented Truck Destinations = 11.9 + 0.38 (Total Dwelling Units) + 0.37 (Commercial Employment)	232.1	0.6472	0.7268	102.72	$r_{12} = 0.721$ $r_{13} = 0.442$ $r_{23} = 0.122$

[a] r_{12} = Correlation between dependent variable and 1st independent variable; r_{13} = Correlation between dependent variable and 2nd independent variable; r_{23} = Correlation between independent variables.

and communication employment. Consumer-related truck trips, in contrast, are best predicted by total dwelling unit measures and values of commercial employment. Finally, from a statistical standpoint, the values of the overall F for both of the stratified equations are significant at higher levels of confidence than that of the total truck equation. The standard error as a proportion of the mean for the industrial equation increased, however.

Columbus. A final attempt at truck trip stratification using land use at destination was made with truck origin-destination data from the 1964 Columbus, Ohio, origin-destination study. Truck trip data for the 765 zone study area containing a population of 780,000 were supplied. In addition, 33 independent variables, including employment by type, commercial and industrial floor area by function, and land use by type, were available on a zonal level. Once again, total internal truck trips were separated into industrial and non-industrial categories. Industrial, commercial, transportation and utilities, water, mining, and agricultural and vacant land uses comprised the industrial category. The non-industrial or consumer-related group was made up of residential, commercial, public facilities, and recreation open space land uses.

The stratified destination land use regression equations for Columbus and their associated statistics are given in Table 4-11. In contrast to the results for both the Flint and Saginaw land use stratifications, however, the stratification for Columbus apparently has not resulted in improved, or even different, prediction equations. The independent variables in the industrial category--industrial

TABLE 4-11

COLUMBUS INTERNAL TRUCK TRIP DESTINATIONS BY LAND USE AT DESTINATION

Regression Equation	Overall F	R^2	Standard Error of Estimate / Mean	Mean ($\bar{Y}$)	Correlation Coefficients[a]
TOTAL Truck Destinations = 71.7 + 0.82 (Industrial Non-Manufacturing Employment) + 0.19 (Commercial and Government Employment)	210.1	0.3554	1.1383	119.15	$r_{12} = 0.455$ $r_{13} = 0.429$ $r_{23} = 0.099$
"Industry"-Oriented Truck Destinations = 16.2 + 0.29 (Industrial Non-Manufacturing Employment) + 0.18 (Communication, Transportation, and Utility Employment)	135.6	0.2625	2.1129	25.95	$r_{12} = 0.431$ $r_{13} = 0.336$ $r_{23} = 0.143$
"Consumer"-Oriented Truck Destinations = 54.6 + 0.51 (Industrial Non-Manufacturing Employment) + 0.18 (Commercial and Government Employment)	203.6	0.3482	1.1537	93.20	$r_{12} = 0.370$ $r_{13} = 0.494$ $r_{23} = 0.099$

[a] r_{12} = Correlation between dependent variable and 1st independent variable; r_{13} = Correlation between dependent variable and 2nd independent variable; r_{23} = Correlation between independent variables.

non-manufacturing employment and communication, transportation, and utility employment--are intuitively logical; industrial non-manufacturing employment, however, also enters the equation used to predict consumer-related truck destinations.

Statistical results for the three equations shown in Table 4-11 also indicate no improvement due to the stratification. The overall F value is higher for the total truck equation than for either of the stratified equations. Correspondingly, values of R^2 are naturally higher for the overall equation and the standard errors are lower.

One possible explanation for the failure of the Columbus case study to indicate any improvements when stratified by land use at destination is the fact that the number of independent variables available for use in the study may have been too great. A total of 33 variables, including 9 employment and 16 floor space or site area variables, was available on a zonal basis. The effect of this fine level of detail may have been an inability of only two variables to account for significant amounts of variation in the stratified truck trip destinations.

Summary

The purpose of this chapter has been to investigate the effects of various stratifications of truck trip ends on the reliability of truck trip generation equations. Three stratification criteria have been employed. Truck trip ends were first stratified by vehicle type, that is single axle trucks versus other than single axle trucks, single unit trucks versus combination units, and so forth. The

regression equations for the stratified data were then compared with the corresponding regression model for the overall truck trips and any improvements, either in the adequacy of the independent variables entering the model or in the statistical validity of the model itself, were noted.

Comparisons of truck trips stratified by vehicle type for three case study cities showed no improvements due to the stratifications. In general, the overall unstratified models were more statistically adequate, and the independent variables most significant in the stratified equations were comparable to those appearing in the total truck model.

Similar results were obtained when total internal truck trips were stratified according to trip purpose. In this case, two general categories were employed. "Goods"-related trips were those trips which had as their primary purpose the pickup or delivery of goods. "Service"-related trips had as their primary purpose the performance of a service function, such as vehicle repair or a service call.

The stratification by truck trip purpose, which was investigated for data from two case study cities, indicated no overall improvements due to the stratification when compared to the overall model. The stratifications by trip purpose did show, however, that goods-related trips do have a strong relationship to either commercial or retail employment while "service"-type trips are most strongly related to measures of total employment. These relationships perhaps could be improved further by deleting those trips made by small truck vehicles for personal business reasons. An additional area of investigation

could focus on the similarity of stratification results over several urban areas. This approach was not possible with the limited data base available for this study. Such comparisons, moreover, would have to be made over areas with identical truck trip purpose categories.

The final criteria on which truck trip ends were stratified was related to the land use at the truck vehicle's destination. Employing a stratification suggested by the literature on urban goods movement forecasting, total truck trip ends were categorized as either "industrial" trips (those made to various types of industrial and manufacturing land uses) or "consumer"-related trips (those made to land uses associated with the resident population of a study area such as residential, retail services, and cultural or recreational).

Results from the stratification by land use at destination, performed for a total of three case study cities, showed some indication of improved results compared to the more general overall models. In two of the three case studies, in fact, significant differences were noted between the stratified and unstratified results, both in terms of the types of independent variables employed and the statistical reliability of the regression equations themselves. Improvements were not discernable in the third case, although it has been suggested that this may be a result of a plethora of independent variables which do not individually contribute significantly to the model.

The relative success of the truck trip models stratified by land use at destination suggests that this approach might be an appropriate area of pursuit if any long-range modeling of urban truck

trip generation is desired. Additional improvements in the adequacy of the stratified models may be realized by the elimination of zones with zero observed trip values as well as those containing unique truck trip generators. This type of refinement, of course, necessitates that the analyst have an intimate knowledge of the area under investigation; this, of course, was not the case with this research.

Applications of this type of modeling of urban truck travel demands, of course, are in the long-range planning area. Improved modeling of truck trips in this time frame may be most appropriate both for evaluating the consequences of alternative future land use plans and for facilitating the development of truck route systems and other network-wide improvements.

CHAPTER 5

THE DEVELOPMENT OF TRUCK TRIP RATES BY GENERALIZED LAND USE CATEGORIES

One of the traditional methods of trip generation analysis outlined in Chapter 2 is land area trip rate analysis, which develops trip rates, usually on a per acre or per square mile basis, for each of the several broad land use categories existing in a transportation study area. These developed rates may then be used to evaluate the impacts which proposed land use changes may have on the traffic patterns or other transportation system characteristics in the area.

The use of land area trip rate analyses may be a valuable tool for transportation systems evaluation in general and for the impact of truck movements in particular on an intermediate scale. Thus, the level of detail for this type of analysis would be more refined than that associated with the regression analysis technique outlined in Chapters 2 and 4 and usually associated with large-scale area-wide forecasting. Similarly, implementation time of the land area trip rate technique would be shorter than the long-term, strategic planning generally associated with the regression analysis procedures, both because of the shorter time required for data collection and model development and the possibility of using "borrowed" rates previously developed for similar urban situations. Time requirements would be more in the tactical planning realm and analysis results would be more readily available and more easily implementable.

The scope and timing of the land area trip rate technique, on the other hand, are respectively less detailed and of longer range than the establishment-level truck trip generation analysis discussed in Chapter 3 and forthcoming in Chapter 6. The trip rate technique thus occupies a somewhat intermediate position in the array of options available for the analysis of urban truck travel demands. Use of truck trip rates by various land use categories would enable local traffic engineers and planners to evaluate the traffic impact of a proposed industrial park, for example, even though the types of establishments eventually to occupy the site could not be immediately determined.

The purpose of this portion of the research is the development of truck trip generation rates by various stratified land use categories. Once again, truck trip origin-destination records from case study cities which collect both destination land use variables and land areas by land use type on an area-wide level are used in the development of the land area truck trip rates. An analysis of these rates, both across land use categories and over the several case study cities, which vary by size, economic base, and geographic location, can not only result in important information for the local impact analyses described above, but may also be valuable input to sketch planning level-type decisions on land use allocation, for example, and may, in fact, be substitutable for other, more detailed, planning relating to truck trips.

In addition to the stratification of the land area trip rates for the four case study cities (Flint, Michigan; Columbus, Ohio; Kenosha, Wisconsin; and Racine, Wisconsin) by land use type, the developed

truck trip rates were also categorized by truck type. Thus, individual rates are available for light, medium, and heavy trucks, as well as for total trucks for each of the case study cities. This breakdown by truck type is particularly important for isolating the impact of the larger and heavier truck vehicles since they are often the critical units in terms of environmental considerations and roadway geometric constraints.

This chapter will begin with a discussion of the findings of the land use trip rate development in each of the four case study cities. A general comparison of the rates will then be made over the case study cities analyzed in this research as well as with the land area truck trip rates developed by previous research and summarized in a latter section of Chapter 2 (pp. 35-40). Because the land area trip rates in each of the case study cities were developed using area-wide land use totals, no estimate of the variance of each of the land area truck trip rates between the study area's analysis zones was possible. In order to allow such an estimate to be made, acreages by land use type, as well as truck trip ends by land use type, for each of the traffic zones in the area would have to be available. Such was not the case, unfortunately, and only area-wide rates are thus reported.

Flint

Truck trip rates by land use and truck type for the 405,367 acre Flint study area are given in Table 5-1 for the nine category land use breakdown coded on the Flint truck origin-destination records. An examination of Table 5-1 reveals that wholesale land uses are the

TABLE 5-1

TRUCK TRIP RATES BY LAND USE
AND TRUCK TYPE IN FLINT
(1966)

Land Use	Truck Trip Ends Per Acre Per Day[a]			
	Light Trucks[b]	Medium Trucks[c]	Heavy Trucks[d]	Total Trucks
Residential	1.68	0.20	0.09	1.97
Manufacturing	10.37	2.06	2.16	14.59
Transportation, Communication, Utilities	0.68	0.28	0.74	1.70
Wholesale	19.05	7.57	3.40	30.02
Retail	11.85	5.60	1.13	18.58
Services	4.92	1.19	0.18	6.29
Cultural, Recreation, Entertainment	0.31	0.10	0.01	0.42
Resource Production and Extraction[e]	0.04	0.01	-[f]	0.05
Undeveloped[g]	0.01	-	-	0.01

[a]Trip rates include both truck origins and destinations.

[b]Light Trucks = all single unit, single rear tire trucks.

[c]Medium Trucks = all single unit, dual rear tire and single unit, 3 and 4 axle trucks.

[d]Heavy Trucks = all combination units.

[e]Includes agricultural land.

[f]Less than 0.01.

[g]Vacant and water areas.

highest generators of truck trips, both overall and for each of the truck type categories, with 30.02 total truck trip ends per acre and 19.05, 7.57, and 3.40 truck trip ends per acre for light, medium, and heavy trucks, respectively. Both retail and manufacturing land uses are also heavy truck trip generators although the retail category has relatively high trip rates for light and medium trucks (11.85 and 5.60 truck trip ends per retail acre, respectively) while the manufacturing land uses have high trip rates for the heavy truck vehicles (2.16 heavy truck trip ends per manufacturing acre), defined in this case as all combination (tractor-trailer) units. The relatively large trip rates for heavy vehicles in both the wholesale and manufacturing categories make sense since these land uses would be expected to produce or attract large shipments of either raw materials or finished products. It should be pointed out, however, that these land uses also generate a substantial number of light and medium truck vehicle trips, indicating the intensity of the overall truck usage taking place on these particular sites.

In contrast to the large truck trip rates for wholesale and manufacturing land uses in Flint, the retail, and to a lesser degree, the services land uses generate primarily smaller truck vehicle trips. This, too, is logical since land uses of this type may be expected to contain comparatively smaller facilities with either service or delivery functions which are conducive to the operation of smaller truck vehicles. Land uses of this type may also have various access constraints, a central business district location, for example, and thus preclude the operation of larger truck vehicles.

With perhaps the exception of residential land, which has some movement of light trucks (1.68 light truck trip ends per residential acre), none of the other land uses in the Flint area generate truck movements of significant magnitude.

Columbus

Table 5-2 contains land area truck trip rates by truck type developed for the Columbus, Ohio study area of 344,111 total acres. Commercial land uses, including both wholesale and retail categories, are seen to have the highest truck trip rates, both overall (21.79 total truck trip ends per commercial acre) and for each individual truck type (11.93, 8.58 and 1.28 truck trip ends per commercial acre for light, medium, and heavy trucks, respectively). Industrial land uses are the second highest generator of truck trips with 6.83 total truck trip ends per industrial acre and once again contain a high percentage of heavy vehicle trips.

None of the other land use types in Columbus have truck trip rates approaching the intensity of the commercial and industrial uses, although communication, transportation, and utilities (2.14 total truck trip ends per acre) and public facilities (1.14 total truck trip ends per acre) land uses have considerably higher rates than the others. Residential uses have a quite low truck trip rate of only 0.97 total truck trip ends per acre; the total rate, moreover, is somewhat spread across all three truck types with an unexpected non-dominance of light truck trips. This low rate may perhaps be due to the residential definition or, more likely, to the inclusion of

TABLE 5-2

TRUCK TRIP RATES BY LAND USE
AND TRUCK TYPE IN COLUMBUS
(1964)

Land Use	Truck Trip Ends Per Acre Per Day[a]			
	Light Trucks[b]	Medium Trucks[c]	Heavy Trucks[d]	Total Trucks
Residential	0.48	0.38	0.11	0.97
Industrial	2.76	2.94	1.13	6.83
Communication, Transportation, Utilities	0.69	0.84	0.61	2.14
Commercial	11.93	8.58	1.28	21.79
Public Facilities	0.52	0.49	0.13	1.14
Recreation, Open Space	0.30	0.23	0.03	0.56
Mining	-[e]	0.01	-	0.01
Agricultural and Vacant	0.01	-	-	0.01
Water	0.28	0.20	0.05	0.53

[a]Trip rates include both truck origins and destinations.

[b]Light Trucks = all panel and pickup trucks.

[c]Medium Trucks = all other commercial trucks except combinations.

[d]Heavy Trucks = all semi and full trailer combinations.

[e]Less than 0.01.

personal business-type truck trips with the home interview survey and their subsequent deletion from the truck survey (on which the truck trip rates are based).

Kenosha

The land area truck trip rates for Kenosha, a city with a 1972 population of 99,664 and a total area of approximately 86 square miles, were developed from truck movement data from the Southeast Wisconsin Regional Planning Commission (SEWRPC) 1972 origin-destination study. Results of the Kenosha analyses are given in Table 5-3. Once again manufacturing (in this case durable manufacturing) and commercial (retail and services) are the dominant land uses in terms of truck trip generations with total truck trip ends per acre of 44.04 and 39.65, respectively. Durable manufacturing has the highest truck trip generation rate overall and is the only category with a significant number of heavy truck trip generations (8.85 heavy truck trip ends per durable manufacturing acre). Commercial retail and services has a high overall rate which is composed primarily of light (16.93 truck trip ends per acre) and medium (22.17 trip ends per acre) truck trips.

The other land use categories with fairly high truck trip rates are commercial wholesale and storage, with a total truck trip rate of 4.98 trip ends per acre consisting mostly of medium truck trips and containing an unexpectedly low rate for heavy truck generations, and nondurable manufacturing, with a total rate of 4.06 truck trip ends per acre primarily composed of medium truck trip ends (3.40 trip ends

TABLE 5-3

TRUCK TRIP RATES BY LAND USE
AND TRUCK TYPE IN KENOSHA
(1972)

Land Use	Truck Trip Ends Per Acre Per Day[a]			
	Light Trucks[b]	Medium Trucks[c]	Heavy Trucks[d]	Total Trucks
Residential	1.20	0.52	-[e]	1.72
Manufacturing-Nondurable	0.56	3.40	0.10	4.06
Manufacturing-Durable and Extractive	18.49	16.70	8.85	44.04
Transportation and Utilities	0.16	0.11	0.10	0.37
Commercial Wholesale and Storage	1.94	3.00	0.04	4.98
Commercial Retail and Services	16.93	22.17	0.55	39.65
Institutional and Government Service	1.35	0.34	-	1.69
Recreation	-	-	-	-
Agricultural and Related	0.02	-	-	0.02
Open Land and Water Areas	-	-	-	-

[a]Trip rates include both truck origins and destinations.

[b]Light Truck = under 8,000 pounds, except farm (under 10,000 pounds).

[c]Medium Truck = 8,000 pounds to 50,000 pounds.

[d]Heavy Truck = over 50,000 pounds.

[e]Less than 0.01.

per acre). Residential land uses have a total rate of 1.72 truck trip ends per residential acre and are composed of mostly light truck trip ends (1.20 light truck trip ends per acre).

Part of the apparent difference in trip rates by land use type between Kenosha and those for Flint and Columbus may be due to the definitions of light, medium, and heavy trucks. The Flint and Columbus origin-destination studies, for example, coded truck vehicles by vehicle type, that is panel and pickup trucks , other single unit vehicles, and all combination units., The SEWRPC coding, by comparison, was according to vehicle weight--light trucks under 8,000 pounds, medium trucks of 8,000 to 50,000 pounds, and heavy trucks over 50,000 pounds. It is thus possible, although not very likely, for some single unit trucks to have a gross weight of over 50,000 pounds and, conversely, for some combination units to weigh less than 50,000 pounds. Tennessee's weight restrictions by vehicle type, for example, show a maximum allowable gross weight of 48,000 pounds for a small truck-tractor semi-trailer combination, the "pup" vehicle being used more frequently in city deliveries (Robicheaux, 1976, p. 204).

Racine

Truck trip rates have also been developed for Racine, Wisconsin, another city in the SEWRPC study area with a 1972 population of 136,952 and an area of 100 square miles. These rates are shown in Table 5-4. Commercial retail and services is the dominant land use for the generation of truck trips in Racine with a total of 42.13 truck trip ends per acre. The retail and services rate, moreover,

TABLE 5-4

TRUCK TRIP RATES BY LAND USE
AND TRUCK TYPE FOR RACINE
(1972)

Land Use	Truck Trip Ends Per Acre Per Day[a]			
	Light Trucks[b]	Medium Trucks[c]	Heavy Trucks[d]	Total Trucks
Residential	0.93	0.36	-[e]	1.29
Manufacturing-Nondurable	1.94	2.00	0.15	4.09
Manufacturing-Durable and Extractive	12.81	8.75	0.36	21.92
Transportation and Utilities	0.27	0.19	0.02	0.48
Commercial Wholesale and Storage	2.69	3.39	0.13	6.21
Commercial Retail and Services	19.07	22.93	0.13	42.13
Institutional and Government Service	2.22	0.82	-	3.04
Recreation	0.03	0.02	-	0.05
Agricultural and Related	0.01	-	-	0.01
Open Land and Water Areas	0.03	0.16	-	0.19

[a]Trip rates include both truck origins and destinations.

[b]Light Truck = under 8,000 pounds, except farm (under 10,000 pounds).

[c]Medium Truck = 8,000 pounds to 50,000 pounds.

[d]Heavy Truck = over 50,000 pounds.

[e]Less than 0.01.

is almost exclusively composed of light (19.07 truck trip ends per acre) and medium (22.93 truck trip ends per acre) truck trips.

Heavy truck trips, in fact, do not appear significant in any of the land use truck trip rates in Racine. Even durable manufacturing, which has the second highest truck trip rate in Racine of 21.92 truck trip ends per acre, and which generates a considerable number of heavy truck trips in Kenosha, has a very small heavy truck trip rate (0.36 heavy truck trip ends per durable manufacturing acre). The low values for heavy truck trips could be due to the economic makeup of the city which may preclude the need for the types of deliveries usually made by heavy trucks. Another explanation could be a large amount of total acreage in durable manufacturing use which would result in a low heavy truck rate. If this were true, however, the rates for all truck types would also be much less; this does not seem to be the case.

Other land use truck trip rates of significance in Racine include a commercial wholesale and storage rate of 6.21 total truck trips per acre and a residential rate of 1.29 total trucks per acre. These seem comparable with the rates for the same categories in Kenosha.

A Comparison of Land Use Truck Trip Rates

In order to generalize about the use of land area truck trip rates for truck travel forecasting, it is necessary to have an indication of the variability of these rates across a variety of urban areas from which such information is available. Unfortunately, land area trip rates for truck movements are available from only a few sources in the

literature on truck travel demand forecasting; these have been summarized and reported in Chapter 2 of this research (pp. 35-40). The previous studies consist of research performed by Wilbur Smith and Associates for a number of urban areas (Smith, 1969, pp. 65-66) and more recent research by Zavattero performed for the Chicago region (1975, p. 6).

In addition to the lack of previously published material on land area truck trip generation rates, the financial constraints and time limitations on this research project limited the analysis to the four previously described urban areas from which data were available.

The results of the comparison of land area truck trip rates for total truck trips are shown in Table 5-5 for both the previously reported research and the research performed by this project. In order to make meaningful comparisons possible, it was necessary to double the rates reported by Smith (for Nashville, Richmond, Baton Rouge, Little Rock, Columbia, and Monroe) and those developed by Zavattero (Chicago) since they reported on either truck trip destinations or truck trips, not on total truck trip ends.

Interpretation of the stability of the trip rates across urban areas is difficult because of the wide variety of land use categories employed. Residential land use is the only common category over all eleven cities. Industrial or manufacturing uses, on the other hand, are sometimes coded as "industrial," sometimes as "manufacturing," and sometimes broken down into durable and nondurable components. The same is true for the commercial uses, which are reported in as many as six different categories, and most of the other uses as well.

TABLE 5-5

COMPARISON OF LAND USE TRUCK TRIP RATES FROM DIFFERENT URBAN AREAS

Land Use	Truck Trip Ends/Acre											
	Chicago IL	Columbus OH	Nashville TN	Flint MI	Richmond VA	Baton Rouge LA	Little Rock AK	Columbia SC	Racine WI	Kenosha WI	Monroe LA	Average
Residential	2.6	1.0	1.8	2.0	2.8	4.0	2.0	2.4	1.3	1.7	3.4	2.27 (0.89)[a]
Industrial		6.8	5.0									5.90 (1.27)
Manufacturing	7.2			14.6	5.2	2.6	0.8	3.0			11.8	6.46 (5.10)
Nondurable Manufacturing									4.1	4.1		4.10 (0.00)
Durable Manufacturing & Extractive									21.9	44.0		32.95 (15.63)
Commercial	28.5	21.8	29.6									26.63 (4.22)
Retail-Wholesale Trade					20.6	67.2	32.0	40.6			70.0	46.08 (21.77)
Wholesale				30.0								30.00[b]
Commercial Wholesale & Storage									6.2	5.0		5.60 (0.85)
Retail				18.6								18.60[b]

TABLE 5-5 (Continued)

Land Use	Truck Trip Ends/Acre											
	Chicago IL	Columbus OH	Nashville TN	Flint MI	Richmond VA	Baton Rouge LA	Little Rock AK	Columbia SC	Racine WI	Kenosha WI	Monroe LA	Average
Commercial Retail & Services									42.1	39.7		40.90 (1.70)
Transportation, Communication & Utilities	2.2	2.1	1.9	1.7								1.98 (0.22)
Transportation & Utilities									0.5	0.4		0.45 (0.07)
Transportation-Warehouse					1.8	8.0		4.6			5.0	4.85 (2.54)
Service				6.3								6.3[b]
Services, Schools, Government					8.0	5.2		6.4			10.4	7.50 (2.25)
Institutional & Government Service									3.0	1.7		2.35 (0.92)

TABLE 5-5 (Continued)

Land Use	Truck Trip Ends/Acre											
	Chicago IL	Columbus OH	Nashville TN	Flint MI	Richmond VA	Baton Rouge LA	Little Rock AK	Columbia SC	Racine WI	Kenosha WI	Monroe LA	Average
Public Buildings	0.8											0.8[b]
Public Land & Buildings			1.0									1.0[b]
Public Facilities		1.1										1.1[b]
Cultural, Recreation, Entertainment				0.4								0.4[b]
Recreation									0.05	--[c]		0.05[b]
Public Open Space	0.06											0.06[b]
Recreation Open Space		0.6										0.6[b]
Resource Production & Extraction				0.05								0.05[b]
Mining		0.01										0.01[b]
Highways & Streets	0.3											0.3[b]
Auto Parking	1.0											1.0[b]
Agricultural & Vacant		0.01										0.01[b]
Agricultural & Related									0.01	0.02		0.02 (0.01)

TABLE 5-5 (Continued)

Land Use	Truck Trips Ends/Acre											
	Chicago IL	Columbus OH	Nashville TN	Flint MI	Richmond VA	Baton Rouge LA	Little Rock AK	Columbia SC	Racine WI	Kenosha WI	Monroe LA	Average
Open Land & Water		0.5							0.2	--		0.02 (0.01)
Other			0.06									0.06[b]
Undeveloped	0.01			0.01								0.01 (0.00)

Sources: Wilbur Smith and Associates. Motor Trucks in the Metropolis. Under commission from the Automobile Manufacturers Association, New Haven, Ct., 1969, p. 65.; David A. Zavattero, "Commercial Vehicle Trip Generation in the Chicago Region," unpublished paper, Chicago Area Transportation Study, June, 1975, p. 6.

[a]Standard Deviation.

[b]Only one observation.

[c]Less than 0.01.

In order to minimize this problem, then, and to make some comparisons as meaningful as possible, the land uses in Table 5-5 have been grouped into ten somewhat similar categories. Residential land use truck trip rates are thus seen to have some stability across all eleven cities, averaging a little more than two total truck trip ends per acre of residential land. Industrial-related land uses, on the other hand, are seen to have no consistent pattern, ranging from 0.8 truck trips per "manufacturing" acre in Little Rock to 44.0 truck trips per "durable manufacturing and extractive" acre in Kenosha. Part of this vast difference in industrial rates may be explained by the exact types of trips to be included in the two different categories; additional differences may be due to the economic makeup, geographic location, and size of the cities being compared. One general conclusion, however, is that, unlike trip rates for passenger travel, truck trip rates exhibit little similarity between urban areas.

It is possible, nevertheless, to draw some general conclusions from the available truck trip rates. Commercial uses, for the most part, exhibit the highest land use truck trip rates, averaging as much as 46 truck trip ends per acre for some retail uses. Industrial-type land uses are the second highest land area truck trip generators, followed by service, transportation, communication and utilities, and residential. All types of trip rates however, with the possible exception of the residential category, show tremendous variability.

Summary

The purpose of this chapter has been to develop land area truck trip rates by land use type for several case study cities. These rates have been developed from origin-destination survey data from four urban areas--Flint, Michigan; Columbus, Ohio; Kenosha, Wisconsin; and Racine, Wisconsin.

An examination of the developed truck trip rates shows that, in general, commercial and industrial land uses are the greatest generators of truck trips. A large amount of variation is apparent, however, with only residential land uses exhibiting any consistency when a comparison across the results of this research and previously reported truck trip rates is made.

Part of the difficulty in comparing land area truck trip rates across several urban areas, and part of the reason for the tremendous variation in the land use truck trip rates, is the differing land use categories used in the various areas under study. Industrial land uses, for example, may be coded as "industrial" in one area, and as "manufacturing," or "durable manufacturing" and "nondurable manufacturing" in another area. Similarly, commercial land uses may be classified into any number of commercial, retail, and wholesale categories. Such a lack of precise definition could be resolved by reliance on one land use coding scheme for all urban areas, such as the one proposed in the Standard Land Use Coding Manual (1969).

An additional problem in definition arises when analyzing the effect of "light," "medium," and "heavy" truck vehicles. Comparisons are likewise not possible in this regard since some studies have

defined "light," "medium," and "heavy" according to vehicle weight while others have used vehicle type as the classifying variable. Here, again, a standard definition is needed.

Perhaps the most significant recommendation to result from this portion of the research is the need for the development of truck trip rates by land use and truck type for additional urban areas from which data may be available. This work would permit the development of an adequate data base for land area truck trip rates and would perhaps enable some generalities to be stated for land area truck trip rates over urban areas of comparable size, economic structure, and so forth. Results comparable to those already available for passenger trip generation by land use may be realized (Trip Generation by Land Use, 1974).

CHAPTER 6

A STUDY OF TRUCK TRIP GENERATION AT THE ESTABLISHMENT LEVEL

The third objective of this research was to develop truck trip generation models based on the business establishment, rather than the individual vehicle, as the unit of analysis. Truck trip generation rates for selected establishment types in each of several case study cities were developed and analyses of the developed rates were made to reveal any applicability to truck travel demand forecasting.

The advantages and applications of the establishment level of truck trip generation analysis, as well as a survey of previous research in this area, have been reported in Chapter 3. The purposes of this chapter are: to report on the selection and description of the study areas used in the analyses; to list the data requirements of the study, describe the data collection instruments used and discuss the administration of the data collection instruments, including pretest and coordination responsibilities; and finally, to report on the results of the data collection effort.

The analyses and discussions of the establishment-level truck trip generation survey are focused on a number of specific areas. First, the aggregate characteristics of the establishment survey are presented. This section includes a discussion of the temporal characteristics of the truck trip movements for each of the three major establishment groupings--wholesale distributors, truck terminals,

and downtown retail establishments. Truck trip variation by day of the week and by time of day for each major establishment group is discussed, and the distribution of truck trip movements both by truck type and by trip purpose is considered.

The second analysis is a discussion of the development of truck trip rates, in terms of floorspace, employment, and truck fleet, for the three establishment groups. In addition to the overall rates for each major group, this section also considers the variation of rates by truck type, sub-establishment type, and establishment size. A series of difference-of-means tests are utilized to discern significant differences in the truck trip rates stratified by each of the above variables.

Part three of the analysis deals with the significance of the independent variables available for truck trip rate development. Both simple linear regression and stepwise multiple regression analyses are employed to aid in the identification of significant variables for use in estimating truck trip ends as well as to determine the feasibility of using highly stratified independent variables (for example, floorspace by functional type) in the analysis.

The establishment sample size requirements for specified truck trip end error rates are discussed in the final section. Using a previous study of error rates associated with automobile travel to special traffic generators as a model, this section attempts to determine how many establishments in each category need to be included in the sample if the truck trip rate for a category is to be within certain specified error limits.

Selection and Description of the Study Areas

The research selected its establishment sample from the available business establishments in four case study cities--Rochester, New York; Knoxville, Tennessee; Saginaw, Michigan; and Modesto, California. Several reasons dictated the selection of these cities for use in the study. First, a wide range of city sizes was desirable if any variation in establishment truck trip rates by city size was to be discerned. The four selected cities thus contained 1970 urbanized area populations ranging from 601,000 in Rochester to 106,000 in Modesto (Population Projections by States, Urbanized Areas, and Other Geographic Areas, 1973). Also, in the selection of the establishment-level case study cities it was desired to obtain a sample of cities with several types of economic base. The selected cities therefore represent a range of city types from heavily industrialized (Rochester), to diversified (Knoxville, Saginaw), to agricultural and trade (Modesto). Finally, some attempt was made to select cities which would represent a variety of geographic locations. Results of this effort are readily apparent.

The remaining portion of this section gives a brief description of each of the four cities selected for the establishment-level truck trip generation study.

Rochester

Rochester, New York, with a 1970 urbanized area population of 601,000, is the third largest city in the state. Located approximately 70 miles east of Buffalo on Lake Ontario, the city is a port on the

St. Lawrence Seaway system as well as being a manufacturing center of some importance.

Categorized in the Nelson classification of cities by functional specialization (1955, pp. 189-210) as a manufacturing city, Rochester is an important producer of photographic film, cameras, office supplies and equipment, clothing, and optical supplies. The city is also an important transportation center being located on the New York State Barge Canal as well as the previously mentioned St. Lawrence Seaway. Over 100 trucking companies have operations located in the city.

Knoxville

With a 1970 urbanized area population of 190,000, Knoxville is the third largest city in Tennessee. The city, which has a diversified functional specialization according to the Nelson classification, is an industrial, commercial, and educational center for East Tennessee. Major industries include textiles and aluminum.

Knoxville is the headquarters for the Tennessee Valley Authority and the main campus of The University of Tennessee is located in the city. Nearby is the city of Oak Ridge where nuclear and other energy-related research is carried on. Knoxville is also somewhat of a tourist center, being located only 25 miles from the entrance to the Great Smoky Mountains National Park.

Saginaw

Saginaw (1970 urbanized area population--148,000) is located in eastern Michigan on the Saginaw River approximately 80 miles northwest of Detroit. The city is highly industrialized, manufacturing

primarily automobile parts and accessories, but the surrounding countryside remains quite agricultural, with sugar beets being the primary farm commodity of the region.

Modesto

Modesto, California is the smallest of the four case study cities selected for the establishment-level truck trip generation study, with a 1970 urbanized area population of 106,000. Modesto is located about 80 miles east of San Francisco and is primarily an agricultural and trade center. The predominant industries include food processing, canning, and packing.

Study Design

Three major business establishment groupings were selected for study in each of the four case study cities. These establishment types were: wholesale distributors, truck terminals, and downtown retail establishments; they were selected for study both because of the significant numbers of truck movements it was assumed they would generate and also because such establishment types were neglected in past studies of urban truck movements which tended to concentrate on the manufacturing sector.

Within each of the three major groupings, an attempt was made to breakdown the sample by establishment subtypes. Thus, for example, the wholesale category includes both wholesale grocery as well as wholesale hardware distributors. Similarly, truck terminals consist of both common carrier and local cartage companies while the downtown

retail category covers an entire range of retail establishments from small specialty shops to large department stores. A total of ten establishments in each sub-category in each of the four case study cities was the anticipated sample size; a total of 120 establishments would thus be represented. As will be shown later, however, the final sample size was considerably less than the 120 originally envisioned.

Data Requirements

The development of establishment-level truck trip generation models requires data on both the number and type of truck trips originating or destined to the establishments as well as the characteristics of the establishments which may be used to model the truck trips. Previous research on truck movements at the establishment level has been characterized by two important factors: 1.) there was significant variability in the day-to-day movements of trucks to or from a particular establishment; and 2.) the number of truck movements at an establishment was best modeled by either floorspace or employment measures of the establishment. Other establishment-related variables, such as sales or profits, were either too difficult to obtain or too uncertain to forecast.

The data requirements of the establishment-level truck trip generation survey therefore centered on the collection of a sufficient number of daily truck movements to account for day-to-day variability in the truck trips and on the determination of both floorspace and employment variables in a sufficient number of subgroups to model

the daily movement of trucks at the establishment level.

It was determined that the collection of daily truck movements over a week's period of time would be sufficient. Since a data collection effort of this magnitude utilizing hired interviewers for a total of 120 establishments in four case study cities was beyond the financial resources of the study, it was decided to employ the establishments themselves as data collectors. This decision, of course, necessitated detailed questionnaire design and the need for considerable coordination efforts.

Data Collection Instrument

The data collection instrument used to record the establishment-level truck trip generation survey information is shown in Appendix B. Because two basic types of information requirements had to be contained on the form, it was divided into two sections. Section I contains information on the surveyed establishment. Thus, for example, it has questions pertaining to the total square feet of establishment floor area for each of several specific functions as well as total employment breakdowns for several employment categories. Section I also contains information on the number of trucks, by truck type, owned or leased by the particular firm. This information has also been shown to be a significant variable in some establishment-level truck trip generation studies (Hutchinson, 1974, pp. 415-416). In addition, schematics of the truck types are provided to aid in the vehicle coding. Finally, Section I attempts to measure the effect of rail access on wholesale and downtown retail operations since the presence of rail access has a

significant impact on the truck trip generating characteristics of an establishment.

Section II of the survey instrument, the truck trip log, collects information on each truck movement, by type, to or from the establishment. Information such as arrival or departure time, truck ownership, truck type, and trip purpose are recorded. Detailed instructions for keeping the truck trip log are provided and a sufficient number of log sheets for the week's movements are bound in booklet form for ease of recording by establishment personnel. Truck schematics are also provided in the log section to aid in vehicle identification.

Administration of the Data Collection Instrument

The survey instrument was pretested on a sample of downtown retail establishments in Knoxville during the week of December 14, 1975. This pre-Christmas Knoxville survey served two purposes. First, it enabled the research team to evaluate the adequacy of the questionnaire and to make required changes before the full-scale survey in the four case study cities in the spring of 1976. The pretest did, in fact, result in some changes in the survey form. The question on rail access was added, for example, and both the truck ownership and truck type categories on the truck trip log were revised to improve the design of the survey.

The second purpose of the Knoxville pre-Christmas survey was to investigate the temporal stability of establishment-level truck trip generation rates by surveying the same establishments over a time period of several months. It was felt that the weeks before the

Christmas holiday retail rush might be a good time to examine truck movements at retail establishments since it was anticipated that truck movements at this time would be greater than at any other time of year.

Both the pre-Christmas Knoxville survey and the full-scale, four city survey in early 1976 were administered by local planning agencies in the respective cities. The research team developed the questionnaire and assisted in technical matters but the day-to-day administrative responsibilities involved in collecting the survey information and coordination with local establishments were handled by local agencies.

The decision to involve local agencies in the administration and coordination of the establishment survey was a good one. Local personnel had the contacts and influence not available to the research team to select establishments for inclusion in the survey sample and to convince local businesses that they stood to benefit, in terms of more efficient truck movements, for example, from the small investment involved in collecting truck movement information over a week's period of time at their respective establishments.

The actual methods employed by the local agencies to request cooperation from the selected establishments in their cities varied. One approach was to invite representatives from the selected sample of establishments to a luncheon where a representative of the research group would explain the purpose of the survey, request the cooperation of the establishments involved, and distribute copies of the survey instrument to be completed by the establishments during a specified time period.

Another approach was to contact selected sample establishments individually. This approach usually involved a visit by an agency representative to the establishment where the survey was explained, the required survey forms delivered, and any questions answered on a face-to-face basis. The agency representative would then return to collect the survey information the week following the data collection.

The actual data collection was usually handled by either one of two establishment employees. The information in Section I of the survey relating to establishment size and work force was usually completed by a member of the firm's management. The truck trip log, on the other hand, Section II of the questionnaire, was generally maintained by someone actually involved on a daily basis with the firm's shipping and receiving functions. For the smaller retail establishments this individual would usually be the store employee responsible for accepting shipments. In the case of the larger firms, a shipping or receiving foreman assumed responsibility for filling out the truck trip log. In some cases, where firms had separate shipping and receiving departments, two separate logs were maintained.

Regardless of the method of data collection utilized, employees of the establishments were able to record truck movements with little disruption of their normal work duties.

Results of the Data Collection Effort

The establishment-level truck trip generation survey was to collect data from a total of 120 establishments made up of equal

numbers of wholesale, truck terminal, and downtown retail categories. Because of a reluctance of some business firms to participate in the survey, the final sample size, both overall and in the three subgroups, did not reach the desired levels. In anticipation of this problem, the survey teams attempted to over-sample where possible in order to increase the total number of establishments surveyed.

The final sample sizes in each category in each of the case study cities are shown in Table 6-1. It can be seen from the table that some cities were more successful than others in attaining the anticipated goal of 30 establishments. Knoxville, in particular, had more than the desired minimums in both the truck terminal and downtown retail categories. Rochester and Saginaw, on the other hand, reached only one-half of their desired totals of 30 establishments and were particularly weak in wholesale responses (only two in Rochester) and truck terminal returns (two in Saginaw). Failure to achieve the desired minimums reflects not only the lack of interest by individual establishments but also the enthusiasm with which the project was received and pursued by officials of the local agencies involved.

Aggregate Characteristics of the Establishment-Level Truck Trip Survey

Before a detailed analysis of the truck trip generating characteristics of wholesale, truck terminals, and downtown retail establishments is made, it is important to consider the aggregate characteristics of the truck movements at each of the three major establishment types. The overall magnitude of the truck trip movements was therefore examined in terms of its temporal stability (both hourly and daily) and its variation according to truck type and trip purpose. The need

TABLE 6-1

ESTABLISHMENT-LEVEL SAMPLE SIZES
BY CATEGORY AND CITY

City	Establishment Category	Anticipated Sample (Number of Establishments)	Actual Sample (Number of Establishments)
Knoxville			
	Wholesale	10	7
	Truck Terminals	10	19
	Downtown Retail	10	12
	Total	30	38
Modesto			
	Wholesale	10	9
	Truck Terminals	10	8
	Downtown Retail	10	15
	Total	30	32
Rochester			
	Wholesale	10	2
	Truck Terminals	10	6
	Downtown Retail	10	7
	Total	30	15
Saginaw			
	Wholesale	10	4
	Truck Terminals	10	2
	Downtown Retail	10	9
	Total	30	15
Totals			
	Wholesale	40	22
	Truck Terminals	40	35
	Downtown Retail	40	43
	Total	120	100

for detailed aggregate truck trip characteristics, particularly hourly variations, is apparent; application of these characteristics may be made when considering operational improvements near major truck generators or when evaluating environmental impacts of proposed truck generating facilities.

Daily Variation of Truck Trips

The average daily total truck trip ends by establishment type for each of the five weekday survey days is shown in Table 6-2. An examination of the table reveals a fairly uniform distribution of truck

TABLE 6-2

AVERAGE DAILY TRUCK TRIP ENDS BY DAY OF THE WEEK AND ESTABLISHMENT TYPE (ALL CITIES COMBINED)

Day	Average Daily Truck Trip Ends Per Day		
	Wholesale Establishments (22)[a]	Truck Terminals (35)	Downtown Retail Establishments (42)
Monday	28.5	43.4	11.5
Tuesday	29.0	47.4	12.1
Wednesday	25.4	47.0	11.5
Thursday	26.5	46.8	12.5
Friday	22.9	45.2	11.5

[a]Number of establishments included in sample.

trip ends over the five survey days for each establishment type. In general, fewer truck movements take place at either the very beginning or very end of the workweek, although this is not always the case. Wholesale establishments, for example, have a higher average number of trips during the early part of the week with the average dropping off as the week progresses and reaching a low point on Friday. This could perhaps be explained by the need to re-stock suppliers early in their workweek. This low number of trips at the end of the week may be further explained if the wholesale establishment is a supplier of perishable items, such as fresh fruits, vegetables, and so forth.

The truck terminals seem to have fairly steady trip movements during the middle three days of the week and a smaller number of trips on either Monday or Friday. Similarly, Monday and Friday have a lower number of average trip ends in the downtown retail category, although Wednesday is also a lower than average day in this group. The somewhat higher averages for Tuesday and Thursday in the downtown retail category may be explained by the large number of small stores included in this category which have no delivery function of their own and only receive supplies once or twice a week.

Average trip ends for weekends were not computed as only the truck terminal category had significant movements on either Saturday or Sunday. Even then, the magnitude of the movements was nowhere near that achieved during the normal workweek.

Hourly Variation by Vehicle Type

Truck movements, like those of automobiles, are not constant throughout the day but vary significantly over any 24-hour period. The

magnitude of the peak truck movements, as well as their time of occurrence, therefore, may have a significant impact on the traffic and congestion problems near heavy truck generators, particularly if truck traffic peaks coincide with those of automobile traffic. An understanding of the hourly distribution of truck traffic at the three major establishment types surveyed in this study, then, may be valuable in the evaluation of the impact of these facilities on the local area and may be used for analyses of operational problems which occur near such facilities.

The distributions of light (all single unit, single tire vehicles), medium (all other single unit vehicles), and heavy (all combination units) truck vehicles by time of day for wholesale establishments, truck terminals, and downtown retail establishments are given in Figures 6-1 through 6-3, respectively. As might be expected, the distributions are quite dissimilar.

Total truck trip ends by time of day at the wholesale establishments, for example, as shown in Figure 6-1, are relatively well spread out between the hours of 5:00 a.m. and 5:00 p.m., with peak movements occurring at 8:00 a.m., 11:00 a.m., and 2:00 p.m. Very few movements at wholesale establishments take place either before 4:00 a.m. or after 7:00 p.m. Truck types peak at different times with the highest percentage of heavy truck movements taking place during the hour ending at 8:00 a.m. while medium-sized trucks peak at 11:00 a.m. and light trucks at 6:00 a.m.

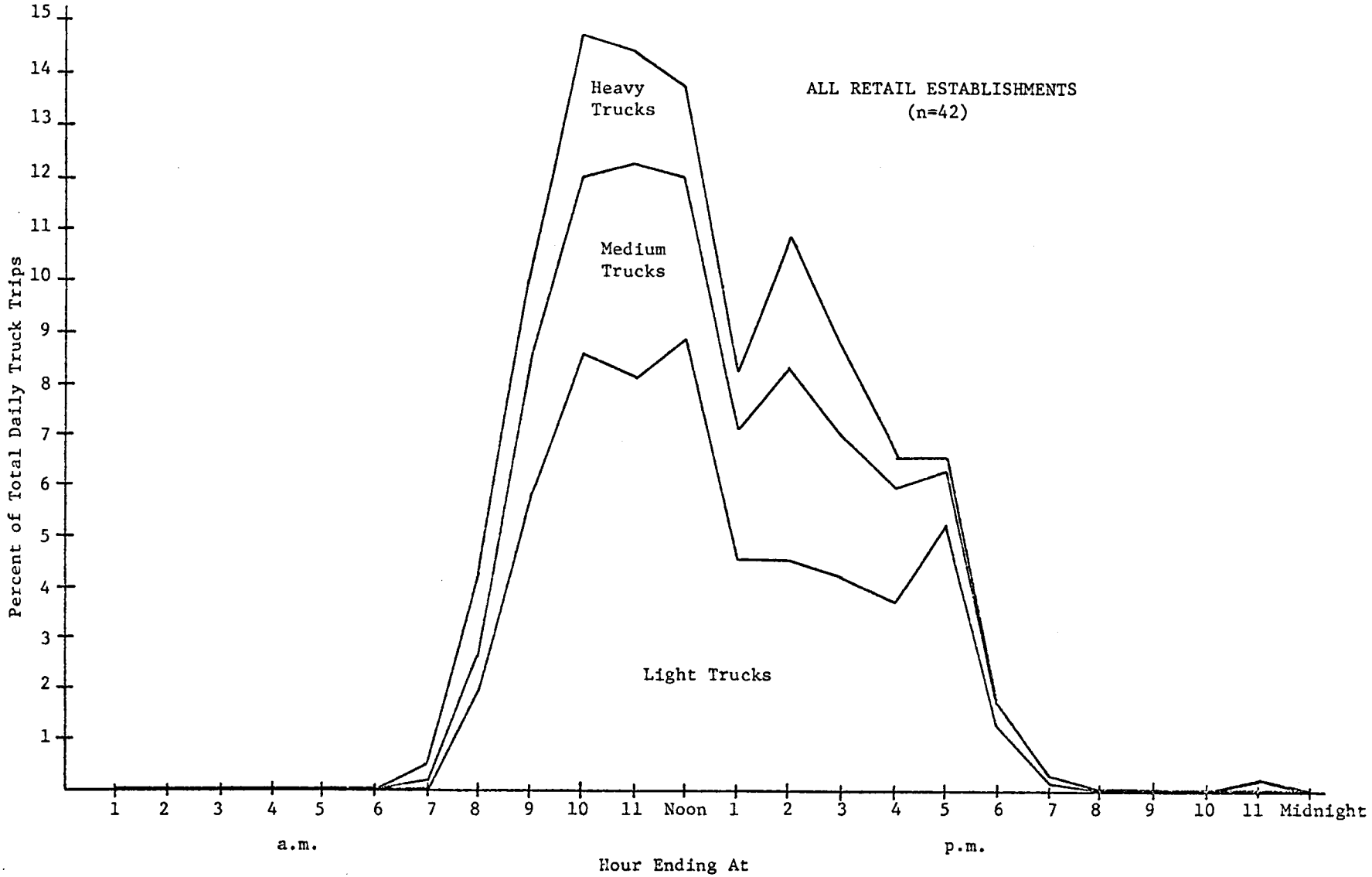


FIGURE 6-1

HOURLY VARIATION OF TRUCK TRIP ENDS BY TRUCK TYPE - WHOLESALE ESTABLISHMENTS

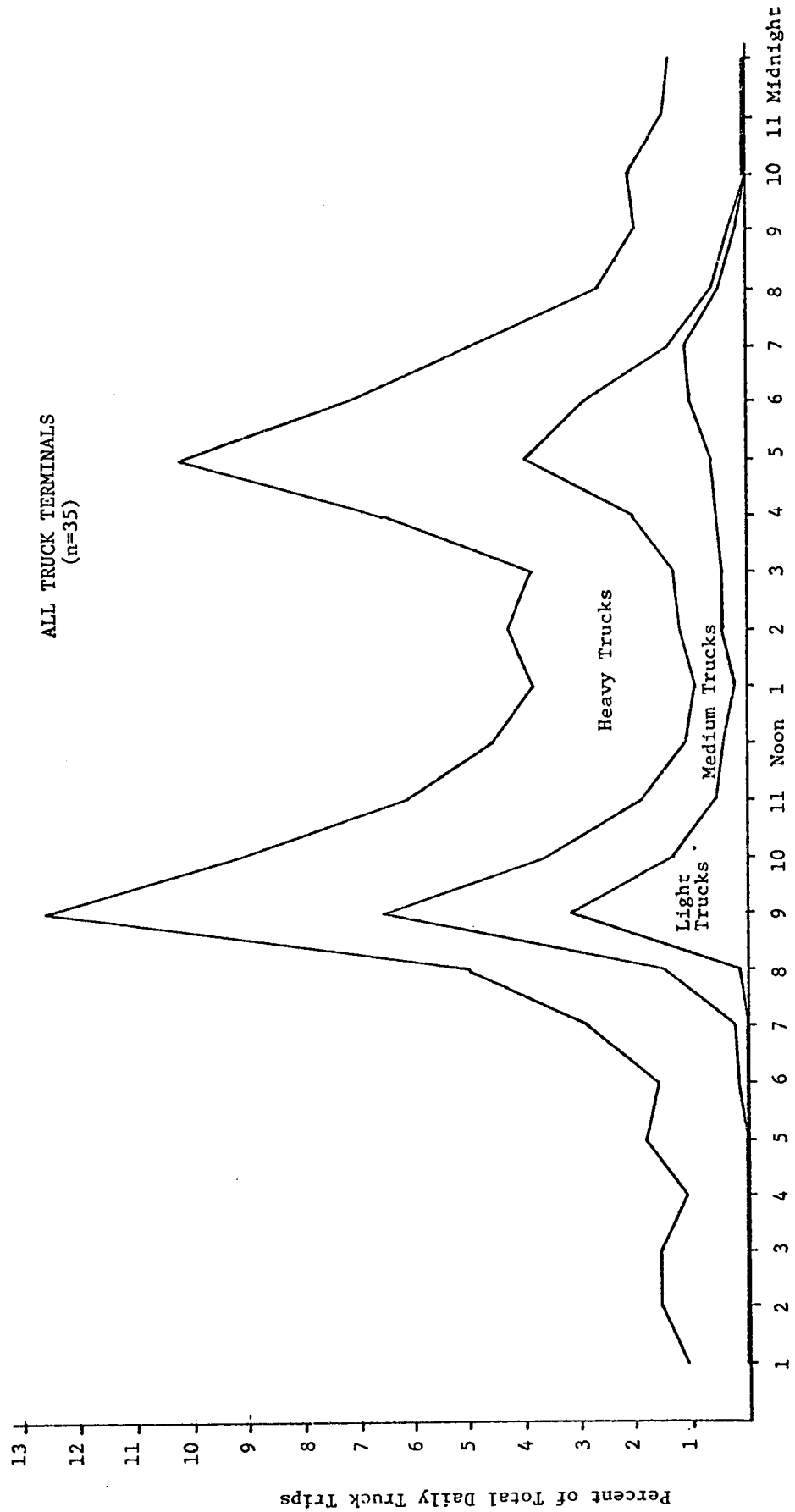


FIGURE 6-2

HOURLY VARIATION OF TRUCK TRIP ENDS BY TRUCK TYPE - TRUCK TERMINALS

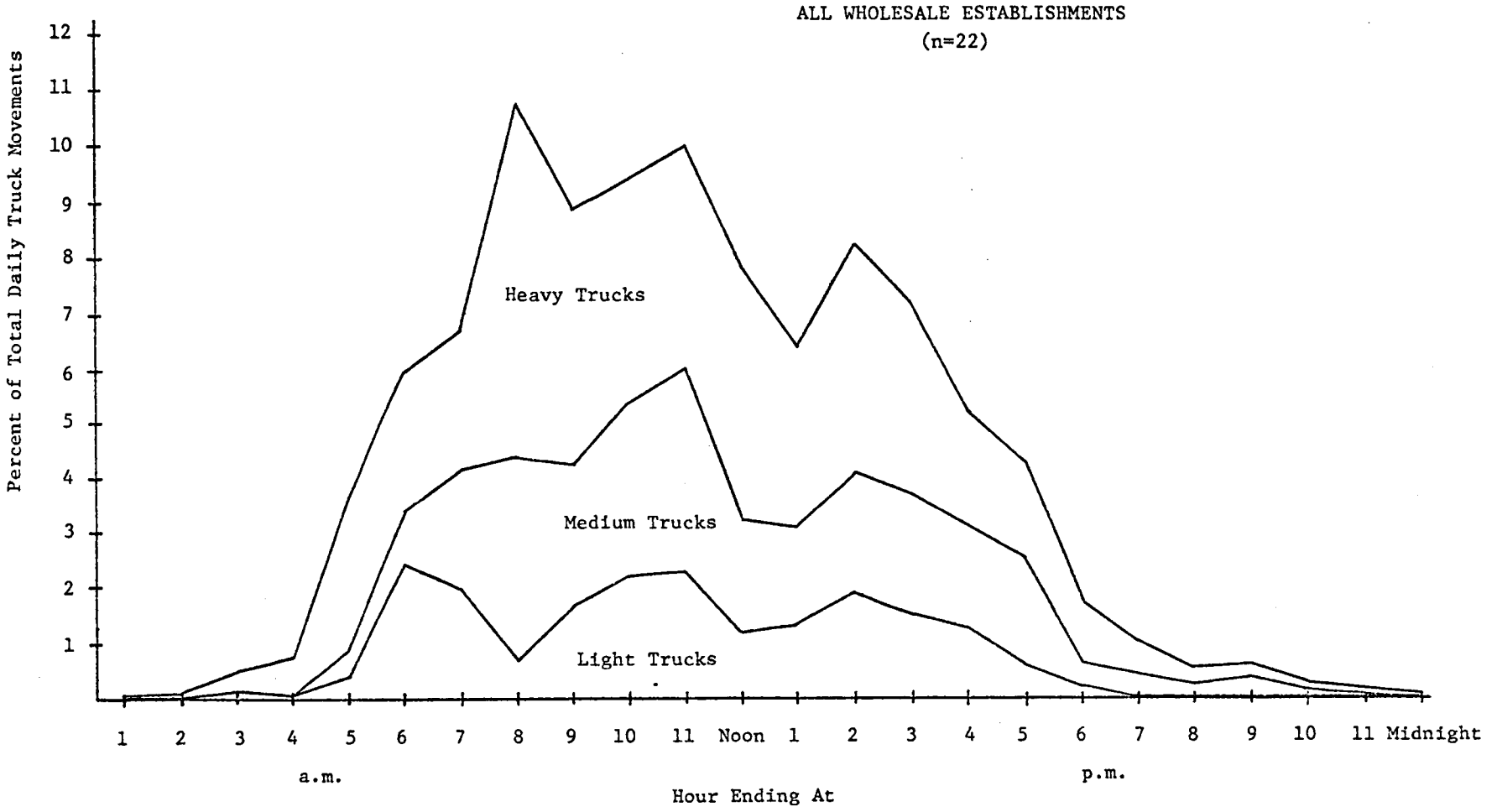


FIGURE 6-3

HOURLY VARIATION OF TRUCK TRIP ENDS BY VEHICLE TYPE - DOWNTOWN RETAIL ESTABLISHMENTS

The distribution of truck trip ends by time of day for the truck terminal category is shown in Figure 6-2. Several characteristics of this figure are readily noticeable. First, two very pronounced peaks occur---during the hours ending at 9:00 a.m. and 5:00 p.m. Secondly, despite the unique peaking characteristics of the truck terminal truck trip ends, some truck movements do take place over the entire 24-hour period. This is in contrast to both the wholesale and downtown retail categories and may be an important concern in evaluating the localized impact of truck terminals.

The final significant feature of the truck terminal truck trip end distribution is that the truck trip ends are made almost entirely by heavy (tractor-trailer) truck vehicles. This is a significant consideration, particularly in terms of local roadway geometrics and noise pollution. The noise problem may be particularly acute during late evening and early morning hours when ambient noise levels are quite low and the truck traffic at the terminals consists exclusively of heavy truck vehicles.

Figure 6-3 shows the hourly distribution of truck trip ends at all downtown retail establishments. It can be seen that the retail trips take place almost entirely during normal working hours--that is between 8:00 a.m. and 5:00 p.m. An extended peak is seen to exist between 9:00 a.m. and noon and a secondary peak occurs at approximately 2:00 p.m. A final characteristic of the truck movements at downtown retail estabishments is that they consist predominately of trips made by light truck vehicles.

Aggregate Distribution by Truck Type

The distribution of truck trip ends by truck type at each of the three major establishment types surveyed may be roughly estimated from the hourly distributions by truck type discussed previously. A more detailed description of the average number of truck trip ends per day by truck type and sub-establishment type, however, may be seen in Table 6-3, which shows the truck trip ends per day for each of six truck types for different establishment categories and sub-categories.

Table 6-3 gives both the average number of truck trip ends per day and the percentage of total truck trip ends per day for not only the total wholesale, truck terminal, and downtown retail categories but also for three sub-categories in the wholesale group (grocery, hardware, and other) and three truck terminal types (common carrier, local cartage, and other). No attempt was made to subdivide the downtown retail category into sub-establishment types because of the wide variety of downtown retail establishments surveyed.

Table 6-3 points out the wide variation in truck trip ends by truck type both across the major establishment categories and within the categories themselves. It can be seen in the wholesale category, for example, that while 58 percent of the truck trip ends at wholesale grocery establishments are made by large tractor-trailer combinations, considerably fewer of these type trip ends occur at the wholesale hardware and other wholesale establishments. On the other hand, wholesale hardware and other wholesale establishments have a significant percentage of their total truck trip ends made by small panel-pickup

TABLE 6-3

AVERAGE TRUCK TRIP ENDS PER DAY BY ESTABLISHMENT TYPE AND TRUCK SIZE (ALL CITIES)

Truck Type	Average Truck Trip Ends Per Day								
	Wholesale Establishments				Truck Terminals				Downtown Retail Establishments (42)
	Grocery (11)[a]	Hardware (3)	Other (8)	Total (22)	Common Carrier (29)	Local Cartage (4)	Other (1)	Total (34)	
Panel-Pickup	3.6 (8.5%)[b]	5.7 (29.7%)	2.3 (31.5%)	3.4 (12.8%)	4.2 (8.9%)	0.9 (4.2%)	11.2 (32.2%)	4.0 (9.1%)	6.1 (51.7%)
Single Unit-Single Rear Tire	0.5 (1.2%)	1.4 (7.3%)	0.2 (2.7%)	0.5 (1.9%)	0.5 (1.1%)	0.8 (3.7%)	1.2 (3.4%)	0.6 (1.4%)	0.6 (5.1%)
Single Unit-Dual Rear Tire	11.5 (27.1%)	8.3 (43.2%)	2.8 (38.4%)	7.9 (29.8%)	7.3 (15.5%)	9.9 (46.3%)	18.6 (53.4%)	8.0 (18.3%)	2.9 (24.6%)
Single Unit-3 & 4 Axle	0.8 (1.9%)	0.1 (0.5%)	0.0 (0.0%)	0.4 (1.5%)	0.4 (0.8%)	1.0 (4.7%)	0.6 (1.7%)	0.5 (1.1%)	0.3 (2.5%)
Small Combination Unit	1.3 (3.1%)	0.5 (2.6%)	0.4 (5.5%)	0.9 (3.4%)	4.6 (9.7%)	1.2 (5.6%)	0.8 (2.3%)	4.0 (9.1%)	0.4 (3.4%)

TABLE 6-3 (continued)

Truck Type	Average Truck Trip Ends Per Day								
	Wholesale Establishments				Truck Terminals				Downtown Retail Establishments (42)
	Grocery (11)[a]	Hardware (3)	Other (8)	Total (22)	Common Carrier (29)	Local Cartage (4)	Other (1)	Total (34)	
Over-the-Road Combination	24.6 (58.0%)	3.1 (16.1%)	1.6 (21.9%)	13.3 (50.2%)	30.2 (64.0%)	7.6 (35.5%)	2.4 (6.9%)	26.7 (61.0%)	1.5 (12.7%)
ALL TRUCKS	42.4 (100%)	19.2 (100%)	7.3 (100%)	26.5 (100%)	47.2 (100%)	21.4 (100%)	34.8 (100%)	43.8 (100%)	11.8 (100%)

[a]Number of observations.

[b]Percent of all trucks in sub-establishment category.

type truck vehicles (29.7 and 31.5 percent, respectively) while only 8.5 percent of the truck trip ends at wholesale grocery establishments are made by panel-pickup vehicles.

A similar situation exists in the breakdown of the truck terminal category. Common carrier terminals--those providing primarily inter-city transportation--have an extremely high percentage (64 percent) of their truck trip ends made by over-the-road tractor trailer units. Local cartage operations, in contrast, which provide primarily local distribution services, have only 35.5 percent of their truck trip ends accounted for by large combination units while over 46 percent of their truck trip ends are made up of single unit, dual rear tire vehicles.

Finally, as was shown in the hourly frequency distribution for downtown retail establishment truck trip ends, almost 52 percent of these trip ends consist of those made by panel-pickup type truck vehicles while only about 13 percent are made by large tractor-trailer units.

Aggregate Distribution by Truck Trip Purpose

The distribution of truck trip ends by establishment and sub-establishment type for the various trip purposes coded in the establishment-level truck trip survey is given in Table 6-4. It can be seen from the table that the trip purpose of "deliver goods" is, in most cases, the most frequently coded purpose. In the wholesale category, for example, the purpose of deliver goods accounts for anywhere from 64 to 77 percent of the total truck trip ends.

TABLE 6-4

AVERAGE TRUCK TRIP ENDS PER DAY BY ESTABLISHMENT TYPE AND TRIP PURPOSE (ALL CITIES)

Trip Purpose	Average Truck Trip Ends Per Day								
	Wholesale Establishments				Truck Terminals				Downtown Retail Establishments (42)
	Grocery (11)[a]	Hardware (3)	Other (8)	Total (22)	Common Carrier (29)	Local Cartage (4)	Other (1)	Total (34)	
Pickup Goods	1.8 (4.2%)[b]	4.9 (25.5%)	0.8 (11.0%)	1.9 (7.2%)	4.4 (9.3%)	2.6 (12.1%)	2.6 (7.5%)	4.1 (9.4%)	1.1 (9.3%)
Deliver Goods	32.6 (76.9%)	12.3 (64.1%)	5.4 (74.0%)	19.9 (75.1%)	17.0 (36.0%)	6.8 (31.6%)	3.0 (8.6%)	15.4 (35.2%)	6.5 (55.1%)
Pickup and Deliver Goods	0.4 (0.9%)	0.8 (4.2%)	0.1 (1.4%)	0.4 (1.5%)	9.7 (20.6%)	2.1 (9.8%)	0.6 (1.7%)	8.5 (19.4%)	1.5 (12.7%)
Service Call	0.2 (0.5%)	0.1 (0.5%)	0.2 (2.7%)	0.1 (0.4%)	0.6 (1.3%)	0.3 (1.4%)	10.2 (29.3%)	0.9 (2.1%)	0.7 (5.9%)
Personal Business	0.1 (0.2%)	0.0 (0.0%)	0.0 (0.0%)	0.1 (0.4%)	0.2 (0.4%)	0.2 (0.9%)	7.2 (20.7%)	0.4 (0.9%)	0.2 (1.7%)
Base of Operations	7.3 (17.2%)	1.1 (5.7%)	0.8 (11.0%)	4.1 (15.5%)	10.1 (21.4%)	7.0 (32.6%)	11.0 (31.6%)	9.7 (22.1%)	1.7 (14.4%)

TABLE 6-4 (continued)

Trip Purpose	Average Truck Trip Ends Per Day								
	Wholesale Establishments				Truck Terminals				Downtown Retail Establishments (42)
	Grocery (11)[a]	Hardware (3)	Other (8)	Total (22)	Common Carrier (29)	Local Cartage (4)	Other (1)	Total (34)	
Other	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	5.3 (11.2%)	2.5 (11.6%)	0.2 (0.6%)	4.8 (11.0%)	0.1 (0.8%)
ALL TRUCKS	42.4 (100%)	19.2 (100%)	7.3 (100%)	26.5 (100%)	47.2 (100%)	21.5 (100%)	34.8 (100%)	43.8 (100%)	11.8 (100%)

[a]Number of observations.

[b]Percent of all trucks in sub-establishment category.

Unfortunately, since both deliveries to and deliveries from the establishment are included in this purpose, it is difficult to determine an exact breakdown except through cross-classification of trip purpose with the trip direction. In any case, however, it is apparent that the delivery of goods is the single most important function of truck trips generated by wholesale establishments.

The delivery function is also of prime importance when the truck trip ends at truck terminals are examined. In the case of truck terminals, however, categories such as "returning to base of operations," "other" (usually a tractor dropping-off an empty trailer), and "pickup and deliver goods" are of some importance.

The retail category, similar to wholesale and truck terminal operations, has deliver goods as the single most important trip purpose, although "base of operations" and "pickup and deliver goods" capture a significant share of the total truck trip ends stratified by trip purpose.

The Development of Establishment-Level Truck Trip Rates

The development of establishment-level truck trip rates, which relate the total number of truck trip ends generated by a particular establishment to various characteristics of the establishment, was one of the basic objectives of this research. The utility of establishment level truck trip rates, whether they be based on floorspace, employment, or some other establishment-level variable, lies in their ability to forecast future truck trip ends given independent estimates of the rate-producing variable.

This section of the research reports on the establishment-level truck trip rates developed from the establishment truck trip survey of three major establishment groups in each of four case study cities. In addition to a further discussion of the average number of trips per day (described in the previous section on aggregate characteristics) for each of the four cities and the three establishment groups, this section develops and discusses truck trip rates based on measures of total floorspace, total employment, and the total number of establishment-owned trucks. One-way analysis of variance is used to test for differences in mean truck trip rates across the three major establishment groups and individual significance tests are used for testing differences between individual pairs of rates. Truck trip rates are also developed by various sub-establishment categories, by truck type for major establishment groups, and by establishment size (as measured by both floorspace and employment). Analysis of variance and other significance tests are again employed to test for significant differences across selected stratified categories.

A Comparison of Establishment Truck Trip Rates from the Case Study Cities

As both a preliminary indication of the truck trip rate types developed in this research and to point out in a general way the relative contributions of each of the four case study cities in which establishment-level truck trip information was collected, this section

portrays the comparison of four developed truck trip rates for the three major establishment groups and the four cities. Because of the small total sample size and the fact that stratification by establishment type and city results in unrealistically small cell frequencies in several cases, the data lends itself only to descriptive techniques. No statistical tests for differences in trip rates over the four urban areas, as originally envisioned, are appropriate.

The results of the trip rate determination, in terms of total truck trip ends per day, per 10,000 square feet of total establishment floor area, per 10 establishment employees, and per establishment-owned truck, are shown in Table 6-5. Perhaps the most significant item to be noted from the table is the tremendous variability of the developed rates across the case study cities despite the sometimes low number of observations and regardless of the establishment grouping. The average number of truck trips per day is perhaps the worst rate on which to make very general comparisons since the total number of trucks per day is in many ways dependent on establishment size as well as function, and no attempt has been made to control for size in this case.

Even when attempts to control for establishment size are considered, however, (that is, by developing truck trip rates based on some "size-measuring" characteristic of the establishment) the variations across cities are still quite large. Again, it is difficult to generalize because of the small number of observations in several categories in some cities, but the rates developed in terms of employees rather than floorspace seem to show more stability across the case study cities for each of the three major establishment groups.

TABLE 6-5

COMPARISON OF ESTABLISHMENT TRUCK TRIP RATES FROM DIFFERENT URBAN AREAS

Truck Trip Rate	Urban Area	Average Truck Trip Rate Value		
		Establishment Groupings		
		Wholesale Operations	Truck Terminals	Downtown Retail
Truck Trip Ends per Day	Knoxville	37.5 (n=7)[a]	51.2 (n=19)	6.8 (n=12)
	Modesto	14.9 (n=9)	25.9 (n=8)	13.7 (n=15)
	Rochester	81.0 (n=2)	29.4 (n=6)	28.3 (n=6)
	Saginaw	5.9 (n=4)	126.0 (n=2)	4.4 (n=9)
	TOTAL	26.5 (n=22)	46.0 (n=35)	11.8 (n=42)
Truck Trip Ends per Day per 10,000 Square Feet of Floor Area	Knoxville	2.9 (n=7)	47.2 (n=17)	1.9 (n=12)
	Modesto	9.6 (n=9)	21.7 (n=8)	12.7 (n=15)
	Rochester	4.0 (n=2)	21.0 (n=6)	2.0 (n=4)
	Saginaw	1.4 (n=4)	53.9 (n=1)	2.4 (n=7)
	TOTAL	5.5 (n=22)	36.1 (n=32)	6.3 (n=38)
Truck Trip Ends per Day per 10 Employees	Knoxville	3.9 (n=6)	13.5 (n=19)	2.3 (n=12)
	Modesto	6.8 (n=9)	16.3 (n=8)	6.6 (n=15)
	Rochester	4.4 (n=2)	11.5 (n=6)	1.2 (n=4)
	Saginaw	2.8 (n=4)	19.1 (n=1)	3.0 (n=6)
	TOTAL	5.0 (n=21)	14.0 (n=34)	4.0 (n=37)
Truck Trip Ends per Day per Truck Owned	Knoxville	2.9 (n=6)	1.7 (n=19)	1.6 (n=12)
	Modesto	2.6 (n=9)	2.0 (n=8)	3.6 (n=15)
	Rochester	2.5 (n=2)	1.6 (n=6)	3.3 (n=5)
	Saginaw	3.0 (n=4)	2.4 (n=1)	1.8 (n=6)
	TOTAL	2.8 (n=21)	1.8 (n=34)	2.6 (n=38)

[a] n = number of observations.

The truck trip rates per truck owned are seen to be quite stable across cities but, although this is an acceptable rate for the wholesale and truck terminal categories, it is somewhat misleading for the downtown retail establishments which are often quite small and, in many cases, do not even own a delivery vehicle.

Stratification of Establishment Truck Trip Rates by Establishment Type

A major concern of this research was whether establishments with different functional characteristics generate truck trips at significantly different rates. Thus, it was hypothesized that wholesale establishments, for example, generate truck trip ends at a different rate than do truck terminals or downtown retail establishments. Further, even within major establishment groupings, there may be significantly different truck trip rates when additional stratifications by establishment type are made. Common carrier truck terminals, for example, may have a higher truck trip rate than local cartage operations.

A summary of the developed trip rates by establishment and sub-establishment type is given in Table 6-6. Truck trip rates are seen to vary considerably not only by major establishment type (wholesale, truck terminal, or downtown retail) but within each of these categories as well. Wholesale grocery establishments, for example, have trip rates higher than those of other wholesale establishments in three of the four trip rate categories. Similarly, common carrier truck terminals have considerably higher truck trip rates in all four trip rate groupings.

TABLE 6-6

STRATIFICATION OF ESTABLISHMENT TRUCK TRIP RATES
BY SUB-ESTABLISHMENT TYPE (ALL CITIES)

Establishment Type	Average Truck Trip Rates			
	Truck Trip Ends per Day	Truck Trip Ends per Day per 10,000 Square Feet of Floor Area	Truck Trip Ends per Day per 10 Employees	Truck Trip Ends per Day per Truck Owned
Wholesale				
Grocery	42.4 (n=11)[a]	6.8 (n=11)	5.6 (n=10)	2.0 (n=10)
Hardware	19.2 (n=3)	2.4 (n=3)	3.2 (n=3)	4.1 (n=3)
Other	7.2 (n=8)	4.8 (n=8)	4.8 (n=8)	3.3 (n=8)
Total	26.5 (n=22)	5.5 (n=22)	5.0 (n=21)	2.8 (n=21)
Truck Terminals				
Common Carrier	49.6 (n=30)	41.2 (n=27)	14.7 (n=29)	1.9 (n=29)
Local Cartage	21.8 (n=4)	8.4 (n=4)	10.3 (n=4)	1.3 (n=4)
Other	34.8 (n=1)	9.0 (n=1)	8.5 (n=1)	0.3 (n=1)
Total	46.0 (n=35)	36.1 (n=32)	14.0 (n=34)	1.8 (n=34)
Downtown Retail				
General Merchandise	17.7 (n=16)	6.0 (n=13)	1.8 (n=13)	1.6 (n=14)
Apparel & Accessories	2.5 (n=12)	2.3 (n=11)	1.5 (n=10)	1.6 (n=10)
Furniture	7.2 (n=5)	2.0 (n=5)	4.8 (n=5)	3.2 (n=5)
Other	16.4 (n=9)	13.9 (n=9)	9.8 (n=9)	5.3 (n=9)
Total	11.8 (n=42)	6.3 (n=38)	4.0 (n=37)	2.6 (n=38)

[a] n = number of observations.

Significant differences in the truck trip rates for the three major establishment groupings may be seen by referring to Table 6-7 which gives the results of a series of difference of means tests for all possible pairs of the three major establishment types. Thus, a significant difference in the number of truck trip ends per day between truck terminals and downtown retail establishments is noted, and, at a lower level of significance, between wholesale establishments and truck terminals as well as between wholesale and downtown retail establishments. Similarly, the truck trip end rates per 10,000 square feet of floor area and per 10 employees are significant for both the wholesale-truck terminal and the truck terminal-downtown retail pairings. The truck trip rates per truck owned also show a significant difference between the wholesale and truck terminal categories, although at a somewhat lower level of significance.

The only rates which do not show a significant difference are those for truck trip ends per 10,000 square feet of floorspace for the wholesale-downtown retail comparison and for truck trip ends per truck owned for both the truck terminal-downtown retail and the wholesale-downtown retail pairings. The fact that the downtown retail category shows up in several of the non-significant pairings suggests that the category itself may be too general and a further stratification by sub-establishment type may be necessary.

When the three major establishment groupings are further stratified, the results of a series of significance tests for variation of trip rates within major establishment categories are as shown in Table 6-8. In the wholesale category, for example, trip rates for

TABLE 6-7

RESULTS OF SIGNIFICANCE TESTS FOR DIFFERENCES IN TRUCK TRIP RATES BETWEEN MAJOR ESTABLISHMENT GROUPS (ALL CITIES)

Truck Trip Rate	Average Truck Trip Rate Values			t Value	2-Tailed Probability
	Wholesale Establishments	Truck Terminals	Downtown Retail Establishments		
Truck Trip Ends per Day	26.5 (22) [a]	46.0 (35)		1.95	0.056
	26.5 (22)		11.8 (42)	-1.71	0.098
		46.0 (35)	11.8 (42)	4.87	0.000
Truck Trip Ends per Day per 10,000 Square Feet of Floor Area	5.5 (22)	36.1 (32)		6.23	0.000
	5.5 (22)		6.3 (38)	0.28	0.783
		36.1 (32)	6.3 (38)	5.86	0.000

TABLE 6-7 (continued)

Truck Trip Rate	Average Truck Trip Rate Values			t Value	2-Tailed Probability
	Wholesale Establishments	Truck Terminals	Downtown Retail Establishments		
Truck Trip Ends per Day per 10 Employees	5.0 (21)	14.0 (34)		7.22	0.000
	5.0 (21)		4.0 (37)	-0.76	0.452
		14.0 (34)	4.0 (37)	7.20	0.000
Truck Trip Ends per Day per Truck Owned	2.8 (21)	1.8 (34)		-2.32	0.027
	2.8 (21)		2.6 (38)	-0.19	0.847
		1.8 (34)	2.6 (38)	-1.67	0.102

[a]number of observations.

TABLE 6-8

RESULTS OF SIGNIFICANCE TESTS FOR DIFFERENCES IN TRUCK TRIP RATES WITHIN ESTABLISHMENT GROUPS (ALL CITIES)

Truck Trip Rate	Major Establishment Grouping	Sub-Establishment Types	t Value	2-Tailed Probability
Truck Trip Ends per Day	Wholesale	Groceries vs. Others (n=11)[a] (n=11)	2.20	0.050
	Truck Terminals	Common Carrier vs. Others (n=30) (n=5)	1.45	0.158
	Downtown Retail	General Merchandise vs. (n=16) Apparel & Accessories (n=12)	2.49	0.025
		General Merchandise vs. (n=16) Other (n=14)	0.51	0.616
		Apparel & Accessories vs. (n=12) Others (n=14)	-1.58	0.138

TABLE 6-8 (continued)

Truck Trip Rate	Major Establishment Grouping	Sub-Establishment Types	t Value	2-Tailed Probability
Truck Trip Ends per Day per 10,000 Square Feet of Floor Area	Wholesale	Groceries vs. Others (n=11) (n=11)	0.75	0.468
	Truck Terminals	Common Carrier vs. Others (n=27) (n=5)	6.02	0.000
	Downtown Retail	General Merchandise vs. (n=13) Apparel & Accessories (n=11)	0.82	0.427
		General Merchandise vs. (n=13) Others (n=14)	-0.60	0.555
		Apparel & Accessories vs. (n=11) Others (n=14)	-1.73	0.108

TABLE 6-8 (continued)

Truck Trip Rate	Major Establishment Grouping	Sub-Establishment Types	t Value	2-Tailed Probability
Truck Trip Ends per Day per 10 Employees	Wholesale	Groceries vs. Others (n=10) (n=11)	0.85	0.403
	Truck Terminals	Common Carrier vs. Others (n=29) (n=5)	1.73	0.093
	Downtown Retail	General Merchandise vs. Apparel & Accessories (n=13) (n=10)	0.46	0.656
		General Merchandise vs. Others (n=13) (n=14)	-2.82	0.012
		Apparel & Accessories vs. Others (n=10) (n=14)	-3.09	0.009

TABLE 6-8 (continued)

Truck Trip Rate	Major Establishment Grouping	Sub-Establishment Types	t Value	2-Tailed Probability
Truck Trip Ends per Day per Truck Owned	Wholesale	Groceries vs. Others (n=10) (n=11)	-2.25	0.041
	Truck Terminals	Common Carrier vs. Others (n=29) (n=5)	1.45	0.158
	Downtown Retail	General Merchandise vs. (n=14) Apparel & Accessories (n=10)	-0.00	0.998
		General Merchandise vs. (n=14) Others (n=14)	-2.68	0.016
		Apparel & Accessories vs. (n=10) Others (n=14)	-2.15	0.030

[a]n = number of observations.

wholesale grocery establishments were tested against rates for all other wholesale establishments (sample size limitations prevented further stratification). In two of the four trip rate categories, truck trip ends per day and per truck owned, significant differences between the rates of the two sub-establishment types were noted.

In the truck terminal category, trip rates for common carrier truck terminal operations were compared with other truck terminals, primarily local cartage operations. Significant differences were found in two of the four developed trip rates--truck trip ends per 10,000 square feet of floor area, and per 10 employees. Only truck trip ends per day and per truck owned did not show significant differences between the two types of truck terminal operations.

Finally, the larger sample size of the downtown retail category permitted the stratification of downtown retail truck trip ends into several distinct functional groups. Thus, comparisons were possible between three types of downtown retail operations--general merchandise, apparel and accessories, and other retail operations.

Results of the t-test for a difference of means between the downtown retail sub-categories shows that general merchandise and apparel and accessory operations differ significantly only in terms of total truck trip ends per day while general merchandise and other downtown retail operations show significantly different mean trip rates per 10 employees and per truck owned. Finally, apparel and accessory and other retail establishments differ only in the mean number of truck trip ends per 10 employees and per truck owned. The lack of significant differences between many of the downtown retail sub-establishment

types suggests that perhaps the establishments should be grouped by establishment size and rates developed for the different size groupings. This stratification is considered in the next section.

Trip Rate Variation By Establishment Size

In addition to variation by establishment and sub-establishment type, truck trip rates may vary by establishment size. This variation could be attributed to economies of scale inherent in the operation of establishments of considerable size. Thus, for example, larger establishments may have sufficient storage area which could preclude the need for frequent deliveries.

The purpose of this section of the research was to examine the variation of the developed truck trip rates by establishment size. Two measures of "size" were employed--total floorspace and total employment--and the developed truck trip rates for each size pairing were tested for significant differences in mean trip rates. Because of the large number of possible pairs in each major establishment group and the different "size" stratifications examined, variations within each major group were considered separately.

Wholesale Establishments. Wholesale establishments were grouped in various size categories based on both total floorspace and total employment. The floorspace size groupings used were: 1.) less than 25,000 square feet of total floorspace; 2.) 25,000 square feet to 100,000 square feet of total floorspace; 3.) over 100,000 square feet of total floorspace. The size groupings by total number of employees were: 1.) 50 or fewer employees; and 2.) more than 50 employees.

The results of a difference of means test applied to all pairs of wholesale establishments grouped by establishment size are given in Table 6-9 for each of the four developed truck trip rates. Only the number of truck trip ends per day, when stratified by establishment size, shows any significant differences in the mean truck trip rates of the different sized establishments. Since the number of truck trip ends per day per establishment is perhaps the least important truck trip rate in terms of forecasting suitability, it would appear that the development of truck trip rates by establishment size is of little value in the analysis of wholesale establishment truck trip rates.

Truck Terminals. Average truck trip ends at truck terminals were computed for several truck terminal sizes. The sizes used were: 1.) total floorspace of less than 10,000 square feet; 2.) total floorspace of 10,000 square feet to 25,000 square feet; 3.) total floorspace over 25,000 square feet; 4.) less than 25 employees; 5.) 25 to 50 employees; and 6.) more than 50 employees. Difference of means tests for these size groupings are given in Table 6-10. Significant differences can be seen for the total number of truck trip ends per day when truck terminals were grouped according to their total number of employees. The trip rates per 10,000 square feet of floor area also show significant differences for some square footage groupings as well as for most of the groupings by number of employees. This would indicate some degree of relationship between the size of the establishment, both in physical space and in number of employees, and the total number of truck trip ends generated by the establishment.

TABLE 6-9

A COMPARISON OF TRUCK TRIP RATES BY ESTABLISHMENT SIZE-WHOLESALE ESTABLISHMENTS (ALL CITIES)

Truck Trip Rate	Establishment Size Range	Truck Trip Rate Values	t Value	2-Tailed Probability
Truck Trip Ends per Day	< 25,000 sq. ft. vs. 25,000 sq. ft. to 100,000 sq. ft.	9.3 vs. 10.7 (n=8)[a] (n=9)	-0.45	0.654
	< 25,000 sq. ft. vs. over 100,000 sq. ft.	9.3 vs. 82.3 (n=8) (n=5)	-3.64	0.022
	25,000 sq. ft. to 100,000 sq. ft. vs. over 100,000 sq. ft.	10.7 vs. 82.3 (n=9) (n=5)	-3.57	0.023
	50 or fewer employees vs. more than 50 employees	9.4 vs. 56.3 (n=14) (n=8)	-2.66	0.032

TABLE 6-9 (continued)

Truck Trip Rate	Establishment Size Range	Truck Trip Rate Values	t Value	2-Tailed Probability
Truck Trip Ends per Day per 10,000 Square Feet of Floor Area	< 25,000 sq. ft. vs. 25,000 sq. ft. to 100,000 sq. ft.	10.5 vs. 2.1 (n=8) (n=9)	1.89	0.101
	< 25,000 sq. ft. vs. over 100,000 sq. ft.	10.5 vs. 3.5 (n=8) (n=5)	1.57	0.160
	25,000 sq. ft. to 100,000 sq. ft. vs. over 100,000 sq. ft.	2.1 vs. 3.5 (n=9) (n=5)	-1.94	0.076
	50 or fewer employees vs. more than 50 employees	7.0 vs. 2.9 (n=14) (n=8)	1.49	0.157

TABLE 6-9 (continued)

Truck Trip Rate	Establishment Size Range	Truck Trip Rate Values	t Value	2-Tailed Probability
Truck Trip Ends per Day per 10 Employees	< 25,000 sq. ft. vs. 25,000 sq. ft. to 100,000 sq. ft.	6.6 vs. 3.4 (n=8) (n=8)	1.81	0.104
	< 25,000 sq. ft. vs. over 100,000 sq. ft.	6.6 vs. 4.8 (n=8) (n=5)	0.81	0.436
	25,000 sq. ft. to 100,000 sq. ft. vs. over 100,000 sq. ft.	3.4 vs. 4.8 (n=8) (n=5)	-1.36	0.202
	50 or fewer employees vs. more than 50 employees	5.4 vs. 4.1 (n=14) (n=7)	0.96	0.347

TABLE 6-9 (continued)

Truck Trip Rate	Establishment Size Range	Truck Trip Rate Values	t Value	2-Tailed Probability
Truck Trip Ends per Day per Truck Owned	< 25,000 sq. ft. vs. 25,000 sq. ft. to 100,000 sq. ft.	3.2 vs. 2.4 (n=8) (n=8)	0.72	0.485
	< 25,000 sq. ft. vs. over 100,000 sq. ft.	3.2 vs. 2.7 (n=8) (n=5)	0.62	0.551
	25,000 sq. ft. to 100,000 sq. ft. vs. over 100,000 sq. ft.	2.4 vs. 2.7 (n=8) (n=5)	-0.30	0.770
	50 or fewer employees vs. more than 50 employees	3.1 vs. 2.2 (n=14) (n=7)	1.38	0.182

[a]n=number of observations.

TABLE 6-10

A COMPARISON OF TRUCK TRIP RATES BY ESTABLISHMENT SIZE-TRUCK TERMINALS (ALL CITIES)

Truck Trip Rate	Establishment Size Range	Truck Trip Rate Values	t Value	2-Tailed Probability
Truck Trip Ends per Day	< 10,000 sq. ft. vs. 10,000 sq. ft. to 25,000 sq. ft.	29.4 vs. 49.5 (n=13)[a] (n=12)	-1.60	0.133
	< 10,000 sq. ft. vs. over 25,000 sq. ft.	29.4 vs. 63.2 (n=13) (n=10)	-2.31	0.044
	10,000 sq. ft. to 25,000 sq. ft. vs. over 25,000 sq. ft.	49.5 vs. 63.2 (n=12) (n=10)	-0.75	0.464
	< 25 employees vs. 25-50 employees	20.8 vs. 44.5 (n=17) (n=10)	-5.30	0.000
	< 25 employees vs. over 50 employees	20.8 vs. 101.2 (n=17) (n=8)	-6.88	0.000
	25-50 employees vs. over 50 employees	44.5 vs. 101.2 (n=10) (n=8)	-4.64	0.001

TABLE 6-10 (continued)

Truck Trip Rate	Establishment Size Range	Truck Trip Rate Values	t Value	2-Tailed Probability
Truck Trip Ends per Day per 10,000 Square Feet of Floor Area	< 10,000 sq. ft. vs. 10,000 sq. ft. to 25,000 sq. ft.	47.8 vs. 35.6 (n=13) (n=12)	1.24	0.228
	< 10,000 sq. ft. vs. over 25,000 sq. ft.	47.8 vs. 15.4 (n=13) (n=7)	3.12	0.006
	10,000 sq. ft. to 25,000 sq. ft. vs. over 25,000 sq. ft.	35.6 vs. 15.4 (n=12) (n=7)	1.81	0.088
	< 25 employees vs. 25-50 employees	23.0 vs. 46.6 (n=17) (n=9)	-2.50	0.019
	< 25 employees vs. over 50 employees	23.0 vs. 57.6 (n=17) (n=6)	-3.70	0.001
	25-50 employees vs. over 50 employees	46.6 vs. 57.6 (n=9) (n=6)	-0.86	0.406

TABLE 6-10 (continued)

Truck Trip Rate	Establishment Size Range	Truck Trip Rate Values	t Value	2-Tailed Probability
Truck Trip Ends per Day per 10 Employees	< 10,000 sq. ft. vs. 10,000 sq. ft. to 25,000 sq. ft.	15.0 vs. 12.5 (n=13) (n=12)	1.07	0.298
	< 10,000 sq. ft. vs. over 25,000 sq. ft.	15.0 vs. 14.6 (n=13) (n=9)	0.14	0.887
	10,000 sq. ft. to 25,000 sq. ft. vs. over 25,000 sq. ft.	12.5 vs. 14.6 (n=12) (n=9)	-0.80	0.432
	< 25 employees vs. 25-50 employees	15.0 vs. 12.7 (n=17) (n=10)	0.94	0.355
	< 25 employees vs. over 50 employees	15.0 vs. 13.6 (n=17) (n=7)	0.49	0.630
	25-50 employees vs. over 50 employees	12.7 vs. 13.6 (n=10) (n=7)	-0.37	0.716

TABLE 6-10 (continued)

Truck Trip Rate	Establishment Size Range	Truck Trip Rate Values	t Value	2-Tailed Probability
Truck Trips per Day per Truck Owned	< 10,000 sq. ft. vs. 10,000 sq. ft. to 25,000 sq. ft.	1.8 vs. 1.5 (n=13) (n=12)	0.85	0.404
	< 10,000 sq. ft. vs. over 25,000 sq. ft.	1.8 vs. 2.1 (n=13) (n=9)	-0.55	0.589
	10,000 sq. ft. to 25,000 sq. ft. vs. over 25,000 sq. ft.	1.5 vs. 2.1 (n=12) (n=9)	-1.12	0.275
	< 25 employees vs. 25-50 employees	2.0 vs. 1.5 (n=17) (n=10)	1.36	0.188
	< 25 employees vs. over 50 employees	2.0 vs. 1.5 (n=17) (n=7)	0.90	0.376
	25-50 employees vs. over 50 employees	1.5 vs. 1.5 (n=10) (n=7)	-0.10	0.925

[a]n=number of observations.

The relationship, however, is a positive one, with the number of truck trip ends increasing as the establishment size increases; economies of scale do not seem to be involved.

Downtown Retail Establishments. Downtown retail establishments were grouped into the following categories based on various measures of establishment size: 1.) less than 10,000 square feet of total floorspace; 2.) 10,000 square feet to 25,000 square feet of total floorspace; 3.) 25,000 square feet to 50,000 square feet of total floorspace; 4.) over 50,000 square feet of total floorspace; 5.) less than 10 employees; 6.) 10 to 50 employees; 7.) over 50 employees. Differences in mean trip rates between each pair of establishment size categories are shown in Table 6-11. Once again, few significant differences in mean trip rates were noted between the various sized categories even though the mean values appear to be quite dissimilar. Part of the difficulty may be due to the relatively small number of observations in each sample category. An additional constraint could be the selection of the category ranges. Finally, the lack of difference in the mean trip rates may be caused by a failure to group according to establishment size by stratifications other than those of the three major establishment groupings. Sample size restrictions, however, precluded this.

Stratification of Truck Trip Rates by Truck Size

The final stratification of truck trip rates presented in this section is by truck size. These results are shown in Table 6-12 and, although no statistical tests are presented, the rates by truck size

TABLE 6-11

A COMPARISON OF TRUCK TRIP RATES BY ESTABLISHMENT SIZE-DOWNTOWN RETAIL ESTABLISHMENTS (ALL CITIES)

Truck Trip Rate	Establishment Size Range	Truck Trip Rate Values	t Value	2-Tailed Probability
Truck Trip Ends per Day	< 10,000 sq. ft. vs. 10,000 sq. ft. to 25,000 sq. ft.	6.0 vs. 13.2 (n=12)[a](n=10)	-0.72	0.486
	< 10,000 sq. ft. vs. 25,000 sq. ft. to 50,000 sq. ft.	6.0 vs. 7.1 (n=12) (n=9)	-0.37	0.717
	< 10,000 sq. ft. vs. > 50,000 sq. ft.	6.0 vs. 20.8 (n=12) (n=11)	-1.67	0.121
	10,000 sq. ft. to 25,000 sq. ft. vs. 25,000 sq. ft. to 50,000 sq. ft.	13.2 vs. 7.1 (n=10) (n=9)	0.63	0.543
	10,000 sq. ft. to 25,000 sq. ft. vs. > 50,000 sq. ft.	13.2 vs. 20.8 (n=10) (n=11)	-0.60	0.556
	25,000 sq. ft. to 50,000 sq. ft. vs. > 50,000 sq. ft.	7.1 vs. 20.8 (n=9) (n=11)	-1.61	0.139
	< 10 employees vs. 10-50 employees	3.1 vs. 12.6 (n=11) (n=16)	-1.53	0.146
	< 10 employees vs. > 50 employees	3.1 vs. 17.3 (n=11) (n=15)	-2.21	0.043
	10-50 employees vs. > 50 employees	12.6 vs. 17.3 (n=16) (n=15)	-0.55	0.590

TABLE 6-11 (continued)

Truck Trip Rate	Establishment Size Range	Truck Trip Rate Values	t Value	2-Tailed Probability
Truck Trip Ends per Day per 10,000 Square Feet of Floor Area	< 10,000 sq. ft. vs. 10,000 sq. ft. to 25,000 sq. ft.	11.0 vs. 7.9 (n=12) (n=10)	0.41	0.684
	< 10,000 sq. ft. vs. 25,000 sq. ft. to 50,000 sq. ft.	11.0 vs. 1.8 (n=12) (n=9)	1.82	0.096
	< 10,000 sq. ft. vs. > 50,000 sq. ft.	11.0 vs. 1.5 (n=12) (n=7)	1.89	0.086
	10,000 sq. ft. to 25,000 sq. ft. vs. 25,000 sq. ft. to 50,000 sq. ft.	7.9 vs. 1.8 (n=10) (n=9)	1.07	0.312
	10,000 sq. ft. to 25,000 sq. ft. vs. > 50,000 sq. ft.	7.9 vs. 1.5 (n=10) (n=7)	1.13	0.287
	25,000 sq. ft. to 50,000 sq. ft. vs. > 50,000 sq. ft.	1.8 vs. 1.5 (n=9) (n=7)	0.84	0.415
	< 10 employees vs. 10-50 employees	4.7 vs. 10.3 (n=11) (n=16)	-1.07	0.299
	< 10 employees vs. > 50 employees	4.7 vs. 1.9 (n=11) (n=11)	1.61	0.138
	10-50 employees vs. > 50 employees	10.3 vs. 1.9 (n=16) (n=11)	1.70	0.110

TABLE 6-11 (continued)

Truck Trip Rate	Establishment Size Range	Truck Trip Rate Values	t Value	2-Tailed Probability
Truck Trip Ends per Day per 10 Employees	< 10,000 sq. ft. vs. 10,000 sq. ft. to 25,000 sq. ft.	5.4 vs. 5.7 (n=12) (n=9)	-0.09	0.926
	< 10,000 sq. ft. vs. 25,000 sq. ft. to 50,000 sq. ft.	5.4 vs. 2.5 (n=12) (n=9)	1.46	0.163
	< 10,000 sq. ft. vs. > 50,000 sq. ft.	5.4 vs. 1.6 (n=12) (n=7)	2.13	0.054
	10,000 sq. ft. to 25,000 sq. ft. vs. 25,000 sq. ft. to 50,000 sq. ft.	5.7 vs. 2.5 (n=9) (n=9)	1.02	0.333
	10,000 sq. ft. to 25,000 sq. ft. vs. > 50,000 sq. ft.	5.7 vs. 1.6 (n=9) (n=7)	1.36	0.211
	25,000 sq. ft. to 50,000 sq. ft. vs. > 50,000 sq. ft.	2.5 vs. 1.6 (n=9) (n=7)	0.88	0.396
	< 10 employees vs. 10-50 employees	5.6 vs. 4.7 (n=11) (n=16)	0.32	0.749
	< 10 employees vs. > 50 employees	5.6 vs. 1.3 (n=11) (n=10)	2.28	0.043
	10-50 employees vs. > 50 employees	4.7 vs. 1.3 (n=16) (n=10)	1.96	0.068

TABLE 6-11 (continued)

Truck Trip Rate	Establishment Size Range	Truck Trip Rate Values	t Value	2-Tailed Probability
Truck Trip Ends per Day per Truck Owned	< 10,000 sq. ft. vs. 10,000 sq. ft. to 25,000 sq. ft.	2.0 vs. 4.4 (n=12) (n=9)	-1.50	0.151
	< 10,000 sq. ft. vs. 25,000 sq. ft. to 50,000 sq. ft.	2.0 vs. 2.4 (n=12) (n=9)	-0.26	0.801
	< 10,000 sq. ft. vs. > 50,000 sq. ft.	2.0 vs. 2.0 (n=12) (n=8)	-0.03	0.978
	10,000 sq. ft. to 25,000 sq. ft. vs. 25,000 sq. ft. to 50,000 sq. ft.	4.4 vs. 2.4 (n=9) (n=9)	1.41	0.178
	10,000 sq. ft. to 25,000 sq. ft. vs. > 50,000 sq. ft.	4.4 vs. 2.0 (n=9) (n=8)	1.94	0.071
	25,000 sq. ft. to 50,000 sq. ft. vs. > 50,000 sq. ft.	2.4 vs. 2.0 (n=9) (n=8)	0.32	0.751
	< 10 employees vs. 10-50 employees	2.4 vs. 2.6 (n=11) (n=16)	-0.17	0.869
	< 10 employees vs. > 50 employees	2.4 vs. 2.9 (n=11) (n=11)	-0.30	0.768
	10-50 employees vs. > 50 employees	2.6 vs. 2.9 (n=16) (n=11)	-0.20	0.842

[a]number of observations.

TABLE 6-12

STRATIFICATION OF ESTABLISHMENT TRUCK TRIP RATES BY ESTABLISHMENT TYPE AND TRUCK SIZE (ALL CITIES)

Truck Trip Rate	Truck Type	Average Truck Trip Rate Value		
		Wholesale Operations	Truck Terminals	Downtown Retail Establishments
Truck Trip Ends per Day	Light	4.0 (n=22)[a]	4.6 (n=34)	6.7 (n=42)
	Medium	8.3 (n=22)	8.5 (n=34)	3.1 (n=42)
	Heavy	14.2 (n=22)	30.8 (n=34)	1.9 (n=42)
	TOTAL	26.5 (n=22)	43.9 (n=34)	11.8 (n=42)
Truck Trip Ends per Day per 10,000 Square Feet of Floor Area	Light	1.6 (n=22)	1.2 (n=31)	4.6 (n=38)
	Medium	2.4 (n=22)	6.7 (n=31)	1.3 (n=38)
	Heavy	1.5 (n=22)	26.7 (n=31)	0.3 (n=38)
	TOTAL	5.5 (n=22)	34.7 (n=31)	6.3 (n=38)
Truck Trip Ends per Day per 10 Employees	Light	1.1 (n=21)	0.8 (n=33)	2.6 (n=37)
	Medium	2.0 (n=21)	3.4 (n=33)	1.1 (n=37)
	Heavy	1.8 (n=21)	9.9 (n=33)	0.3 (n=37)
	TOTAL	5.0 (n=21)	14.1 (n=33)	4.0 (n=37)
Truck Trip Ends per Day per Truck Owned	Light	2.5 (n=12)	1.2 (n=14)	2.9 (n=21)
	Medium	1.6 (n=15)	1.6 (n=28)	3.4 (n=10)
	Heavy	2.5 (n=9)	2.0 (n=33)	1.4 (n=3)
	TOTAL	2.8 (n=21)	1.8 (n=33)	2.6 (n=38)

[a] n=number of observations.

confirm previously discussed topics such as the dominance of heavy truck operations at truck terminals and the significant number of light truck trip ends generated by downtown retail establishments.

The Significance of Independent Variables Used in Truck Trip Rate Development

Truck trip rates by establishment type were developed in the previous section based on three independent establishment-level variables--floorspace, number of employees, and number of establishment-owned trucks. Although significant differences between the developed trip rates for several establishment and sub-establishment types were noted, no attempts were made to determine which independent variables were most valuable in estimating truck trip ends.

The purpose of this section of the research is to determine which of the available independent variables is of greatest importance in estimating the total number of truck trip ends per day for each of the major establishment groups studied. Simple linear regression is employed to determine the single most important independent variable for estimating truck trip ends and to develop simple linear regression equations based on that variable. Stepwise multiple regression is used for ascertaining the added importance of each additional variable to the regression equation. Stepwise multiple regression is also employed to determine if the breakdown of floorspace, employment, and trucks owned by type results in improved models.

Truck Trip Ends Versus Total Floorspace, Employment, and Establishment-Owned Trucks

Simple linear regressions of total truck trip ends per day on total square feet of floorspace, total employment, and total establishment-owned trucks were performed for each of the three major establishment groupings--wholesale operations, truck terminals, and downtown retail establishments. The resulting regression equations, along with their associated coefficient of multiple determination, standard error of the estimate as a proportion of the mean, and significance (F value), are shown in Table 6-13. The combined correlation matrix for the three regression runs is given in Table 6-14.

Table 6-13 indicates that, although truck trip ends per day at wholesale operations are highly related to all three independent variables, total square feet of floorspace is the best single estimator, as measured by R^2, standard errors, and F-levels, of the total number of truck trip ends per day at wholesale establishments. In the truck terminal category, however, only one of the independent variables--total employment--is a good estimator of total truck trip ends per day. The correlation matrix shows that total square feet of floorspace is almost completely unrelated to total truck terminal truck trip ends and, in fact, a significant regression is not even achieved. Finally, in the downtown retail category it can be seen that none of the regression equations is of high quality. The floorspace and employment equations, in fact, do not yield significant regressions and, while the total trucks owned equation does result in a significant equation and a fairly good value of R^2, the standard error is quite

TABLE 6-13

RESULTS OF SIMPLE LINEAR REGRESSION OF TOTAL TRUCK TRIPS PER DAY WITH TOTAL FLOORSPACE, TOTAL EMPLOYMENT, OR TOTAL TRUCKS OWNED (ALL CITIES)

Establishment Grouping	Independent Variable	Regression Equation	R^2	Standard Error of Estimate / Mean	F
Wholesale Operations (n=21)[a]	Total Square Feet of Floorspace (X_1)	$\hat{Y}_W = -1.39 + 0.00035X_1$	0.90	0.45	166.9
	Total Employment (X_2)	$\hat{Y}_W = 7.25 + 0.29X_2$	0.81	0.61	83.2
	Total Trucks Owned (X_3)	$\hat{Y}_W = 1.21 + 2.07X_3$	0.89	0.47	150.8
Truck Terminals (n=32)	Total Square Feet of Floorspace (X_4)	$\hat{Y}_T = 43.7 - 0.00003X_4$	0.00098	0.84	-[b]
	Total Employment (X_5)	$\hat{Y}_T = 4.24 + 1.17X_5$	0.74	0.42	87.9
	Total Trucks Owned (X_6)	$\hat{Y}_T = 26.8 + 0.45X_6$	0.24	0.73	9.57

TABLE 6-13 (continued)

Establishment Grouping	Independent Variable	Regression Equation	R^2	Standard Error of Estimate / Mean	F
Downtown Retail Establishments (n=37)	Total Square Feet of Floorspace (X_7)	$\hat{Y}_R = 6.28 + 0.00011X_7$	0.03	1.79	1.15[c]
	Total Employment (X_8)	$\hat{Y}_R = 7.75 + 0.04X_8$	0.01	1.80	-[b]
	Total Trucks Owned (X_9)	$\hat{Y}_R = 2.38 + 3.63X_9$	0.48	1.32	31.7

[a] n=number of observations.

[b] less than 1.0.

[c] not significant.

TABLE 6-14

COMBINED CORRELATION MATRIX OF
TOTAL TRUCK TRIPS PER DAY BY
ESTABLISHMENT GROUP WITH TOTAL FLOORSPACE, TOTAL
EMPLOYMENT OR TOTAL TRUCKS OWNED

	Y_W	Y_T	Y_R	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
Y_W	1.00	-	-	0.95	0.90	0.94	-	-	-	-	-	-
Y_T	-	1.00	-	-	-	-	-0.03	0.86	0.49	-	-	-
Y_R	-	-	1.00	-	-	-	-	-	-	0.18	0.11	0.69
X_1	0.95	-	-	1.00	0.94	0.93	-	-	-	-	-	-
X_2	0.90	-	-	0.94	1.00	0.96	-	-	-	-	-	-
X_3	0.94	-	-	0.93	0.96	1.00	-	-	-	-	-	-
X_4	-	-0.03	-	-	-	-	1.00	-0.04	0.01	-	-	-
X_5	-	0.86	-	-	-	-	-0.04	1.00	0.73	-	-	-
X_6	-	0.49	-	-	-	-	0.01	0.73	1.00	-	-	-
X_7	-	-	0.18	-	-	-	-	-	-	1.00	0.59	0.20
X_8	-	-	0.11	-	-	-	-	-	-	0.59	1.00	0.13
X_9	-	-	0.69	-	-	-	-	-	-	0.20	0.13	1.00

high. In the case of the trucks-owned equation, moreover, the fact that many of the smaller downtown retail establishments do not own or operate a truck would result in inaccurate estimates in many cases.

When the three independent variables are added to the regression equation in a stepwise manner, little improvement in the models is seen. Interpretation problems sometimes result, moreover, because of the effects of colinear variables.

The results of the stepwise multiple regression for the three "total" variables and the three establishment groups are shown in Table 6-15. The minor improvements mentioned above, in terms of R^2 increase and standard error decrease, can be seen for wholesale establishments but the correlation coefficients in the correlation matrix must be examined for colinearity. No improvements in the models are noted for either the truck terminal or downtown retail categories. The downtown retail equation, in fact, because of the restrictions on the F-to-enter value in the stepwise procedure, computes only a simple linear model. Because of the added effort involved in forecasting additional independent variables and the minimal improvements resulting from their use, simple linear regression models are probably preferable for use at least in the case of wholesale and truck terminal establishments in estimating truck trip ends at the establishment level.

Truck Trip Ends Versus Floorspace, Employment, and Establishment-Owned Trucks by Type

The final consideration in this section of the research was to determine if the stratification of the independent variables by

TABLE 6-15

STEPWISE MULTIPLE REGRESSION OF TOTAL TRUCK TRIPS PER DAY VERSUS TOTAL FLOORSPACE, TOTAL EMPLOYMENT AND TOTAL TRUCKS OWNED (ALL CITIES)

Establishment Grouping	Step Number	Variable Added	Overall F	R^2	R^2 Increase	Standard Error of Estimate / Mean	Constant	b_1	b_2
Wholesale Operations (Y_W) (n=21)[a]	1	Total Floorspace in Square Feet (X_1)	166.9	0.90	0.90	0.45	-1.39	0.00035	
	2	Total Trucks Owned (X_3)	111.7	0.93	0.03	0.40	-1.17	0.00020	0.99
Truck Terminals (Y_T) (n=32)	1	Total Employees (X_5)	87.9	0.74	0.74	0.42	4.24	1.17	
	2	Total Trucks Owned (X_6)	54.2	0.79	0.05	0.39	4.21	1.47	-0.28
Downtown Retail Establishments (Y_R) (n=37)	1	Total Trucks Owned (X_9)	31.7	0.48	0.48	1.32	2.38	3.63	

[a] n=number of observations.

functional type and their entry into a stepwise regression equation would result in improved models. Accordingly, total floorspace, total employment, and total establishment-owned trucks were divided into the several functional sub-categories listed in Table 6-16 and stepwise multiple regression analyses for each establishment type were performed.

Results of the regressions for floorspace by type, employment by type, and establishment-owned trucks by type are given in Tables 6-17, 6-18, and 6-19, respectively. The corresponding correlation matrices are shown in Tables 6-20, 6-21, and 6-22. In the models using floorspace by type given in Table 6-17, it can be seen that, in the case of wholesale establishments, the use of indoor storage as an independent variable results in a slightly better model than that obtained by use of only total floorspace (see Table 6-13, p. 184). In the truck terminal category, a two variable model using both production and office floorspace is a vast improvement over the total floorspace model given in Table 6-13. Finally, the use of floorspace by type for the downtown retail establishments is seen to be little better than that obtained with the total floorspace model. As before, a significant regression is not even achieved.

The multiple regression models using stratified values of employment as independent variables are given in Table 6-18. Once again, for wholesale operations a two variable model using both total employees and production employees is a considerable improvement over the univariate model using total employees alone. Additional variables added to the wholesale model, however, add little and, in fact, confound the results by introducing colinear variables.

TABLE 6-16

FLOORSPACE, EMPLOYMENT, AND TRUCK TYPE BREAKDOWNS
USED IN MULTIPLE REGRESSION ANALYSES

Total Floorspace	Production Floorspace Sales Floorspace Indoor Storage Floorspace Outdoor Storage Floorspace Total Storage Floorspace Office Floorspace Other Floorspace
Total Employment	Production Employment Sales Employment Clerical and Office Employment Management and Supervisory Employment Maintenance Employment Other Employment
Total Establishment-Owned Trucks	Panel or Pickup Trucks Other Single-Unit, Single Rear Tire Trucks Single-Unit, Dual Rear Tire Trucks Single-Unit, 3 and 4 Axle Trucks Small Truck Tractor, Semi-Trailer Combination Over-the-Road Truck Tractor, Semi-Trailer Combination

TABLE 6-17

STEPWISE MULTIPLE REGRESSION OF TOTAL TRUCK TRIPS
PER DAY VERSUS FLOORSPACE BY TYPE
(ALL CITIES)

Establishment Grouping	Step Number	Variable Added	Overall F	R^2	R^2 Increase	Standard Error of Estimate / Mean	Constant	b_1	b_2
Wholesale Operations (Y_{WF}) (n=22)[a]	1	Indoor Storage in Square Feet (X_{10})	219.6	0.92	0.92	0.41	2.02	0.00036	
Truck Terminals (Y_{TF}) (n=32)	1	Production Floorspace in Square Feet (X_{12})	42.4	0.58	0.58	0.54	19.2	0.00463	
	2	Office Floorspace in Square Feet (X_{13})	49.8	0.77	0.19	0.41	7.86	0.00310	0.02
Downtown Retail Establishments (Y_{RF}) (n=38)	1	Production Floorspace in Square Feet (X_{15})	2.68[b]	0.07	0.07	1.78	8.19	0.00045	

[a] n = number of observations.

[b] not significant.

TABLE 6-18

STEPWISE MULTIPLE REGRESSION OF
TRUCK TRIPS PER DAY VERSUS EMPLOYMENT BY TYPE (ALL CITIES)

Establishment Grouping	Step Number	Variable Added	Overall F	R^2	R^2 Increase	Standard Error of Estimate / Mean	Constant	b_1	b_2	b_3
Wholesale Operations (Y_{WE}) (n=21)[a]	1	Total Employees (X_2)	83.2	0.81	0.81	0.61	7.26	0.29		
	2	Production Employees (X_{19})	151.9	0.94	0.13	0.34	-1.01	0.28	0.54	
	3	Maintenance Employees (X_{20})	122.7	0.96	0.02	0.31	-1.90	0.27	0.39	5.02
Truck Terminals (Y_{TE}) (n=34)	1	Total Employees (X_5)	85.0	0.73	0.73	0.43	3.98	1.19		
	2	Production Employees (X_{22})	52.9	0.77	0.04	0.40	5.12	0.90	0.56	
Downtown Retail Establishments (Y_{RE}) (n=37)	1	Production Employees (X_{25})	3.01[b]	0.08	0.08	1.74	8.11	0.33		

[a] n=number of observations.

[b] not significant.

TABLE 6-19

STEPWISE MULTIPLE REGRESSION OF
TRUCK TRIPS PER DAY VERSUS TRUCKS OWNED BY TYPE (ALL CITIES)

Establishment Grouping	Step Number	Variable Added	Overall F	R^2	R^2 Increase	Standard Error of Estimate / Mean	Constant	b_1	b_2	b_3	b_4
Wholesale Operations (Y_{WT}) (n=21)[a]	1	Total Trucks (X_3)	150.8	0.89	0.89	0.47	1.21	2.07			
	2	Panel, Pickup Trucks (X_{28})	92.9	0.91	0.02	0.43	-0.20	1.91	2.08		
Truck Terminals (Y_{TT}) (n=34)	1	Single-Unit, Dual Rear Tire Trucks (X_{31})	25.7	0.45	0.45	0.61	20.3	4.82			
	2	Total Trucks (X_6)	25.0	0.62	0.17	0.52	7.74	4.49	0.40		
	3	Small Tractor Trailers (X_{32})	27.0	0.73	0.11	0.44	0.16	4.02	0.38	2.48	
	4	Panel, Pickup Trucks (X_{33})	26.4	0.78	0.05	0.40	-3.28	4.96	0.51	2.77	-12.3
Downtown Retail Establishments (Y_{RT}) (n=38)	1	Panel, Pickup Trucks (X_{35})	62.4	0.63	0.63	1.13	4.68	3.52			

[a] n=number of observations.

TABLE 6-20

COMBINED CORRELATION MATRIX OF
TOTAL TRUCK TRIPS PER DAY BY ESTABLISHMENT
GROUP WITH FUNCTIONAL BREAKDOWNS OF FLOORSPACE

	Y_{WF}	Y_{TF}	Y_{RF}	X_{10}	X_{12}	X_{13}	X_{15}
Y_{WF}	1.00	-	-	0.96	-	-	-
Y_{TF}	-	1.00	-	-	0.76	0.76	-
Y_{RF}	-	-	1.00	-	-	-	0.26
X_{10}	0.96	-	-	1.00	-	-	-
X_{12}	-	0.76	-	-	1.00	0.50	-
X_{13}	-	0.76	-	-	0.50	1.00	-
X_{15}	-	-	0.26	-	-	-	1.00

TABLE 6-21

COMBINED CORRELATION MATRIX OF
TOTAL TRUCK TRIPS PER DAY BY ESTABLISHMENT
GROUP WITH FUNCTIONAL BREAKDOWNS OF EMPLOYMENT

	Y_{WE}	Y_{TE}	Y_{RE}	X_2	X_{19}	X_{20}	X_5	X_{22}	X_{25}
Y_{WE}	1.00	-	-	0.90	0.45	0.45	-	-	-
Y_{TE}	-	1.00	-	-	-	-	0.85	0.75	-
Y_{RE}	-	-	1.00	-	-	-	-	-	0.28
X_2	0.90	-	-	1.00	0.10	0.14	-	-	-
X_{19}	0.45	-	-	0.10	1.00	0.67	-	-	-
X_{20}	0.45	-	-	0.14	0.67	1.00	-	-	-
X_5	-	0.85	-	-	-	-	1.00	0.70	-
X_{22}	-	0.75	-	-	-	-	0.70	1.00	-
X_{25}	-	-	0.28	-	-	-	-	-	1.00

TABLE 6-22

COMBINED CORRELATION MATRIX OF
TOTAL TRUCK TRIPS PER DAY BY ESTABLISHMENT
GROUP WITH FUNCTIONAL BREAKDOWNS OF TRUCKS OWNED

	Y_{WT}	Y_{TT}	Y_{RT}	X_3	X_{28}	X_{31}	X_6	X_{32}	X_{33}	X_{35}
Y_{WT}	1.00	-	-	0.94	0.55	-	-	-	-	-
Y_{TT}	-	1.00	-	-	-	0.67	0.49	0.48	0.38	-
Y_{RT}	-	-	1.00	-	-	-	-	-	-	0.80
X_3	0.94	-	-	1.00	0.43	-	-	-	-	-
X_{28}	0.55	-	-	0.43	1.00	-	-	-	-	-
X_{31}	-	0.67	-	-	-	1.00	0.11	0.20	0.49	-
X_6	-	0.49	-	-	-	0.11	1.00	0.08	0.49	-
X_{32}	-	0.48	-	-	-	0.20	0.08	1.00	0.24	-
X_{33}	-	0.38	-	-	-	0.49	0.49	0.24	1.00	-
X_{35}	-	-	0.80	-	-	-	-	-	-	1.00

The truck terminal model, on the other hand, benefits little from the stratification of employment variables. The same may be said of the downtown retail model; this category has, in fact, so far been inadequately modeled regardless of the stratification employed.

The final stratification of independent variables--establishment-owned trucks by truck type--is shown in Table 6-19. Some improvements are seen in the truck terminal category where the addition of several truck-type variables to the model improves both R^2 and standard error as a proportion of the mean values without introducing colinear variables. The downtown retail category model is also improved for the first time, with use of the panel-pickup truck category resulting in an acceptable model. The previous caution regarding the number of downtown retail establishments without their own truck delivery vehicles should be kept in mind, however.

Summarizing briefly, it appears that simple linear regression models using either total floorspace or total employment as independent variables are adequate for use in most establishment-level truck trip generation modeling. Although stratification of independent variables by functional subtype and their subsequent use in multiple regression equations results in improved models in some cases, the resources necessary to obtain independent variables stratified by type must be weighed against their added utility over univariate models.

Sample Size Requirements for Specified Truck Trip End Error Limits

The truck trip end rates developed in previous sections of this chapter--truck trip ends per 10,000 square feet of floorspace, per

10 employees, and per establishment-owned truck--are based on a limited number of establishment observations in each of the three major establishment categories--wholesale operations, truck terminals, and downtown retail establishments. The number of observations in each category--the sample size--is a determiner of the accuracy with which the sample mean approximates the true population mean for the particular establishment category under consideration. If it is desired that the sample mean (the estimated number of truck trip ends per day based on a particular truck trip rate from the establishment survey) deviate from the population mean (the true number of truck trips per day at a particular establishment) by only a certain amount, then a minimum sample size required to stay within the specified error limits may be determined, given the maximum value of the independent variable available for the trip rate determination. Similarly, given a specified error rate in terms of truck trip ends per day and a sample size, the truck trip rates which most accurately replicate the total truck trip ends may be determined.

This section of the research calculates minimum sample sizes, in terms of the number of establishments in a specified establishment category, required to produce truck trip end estimates in terms of truck trip ends per day, given a specified error limit, a maximum value of a rate-producing variable, and a specified truck trip rate. The methodology employed is based on that developed for an analysis of the error rates associated with daily automobile traffic to special traffic generators in West Virginia (Neumann and Deshpande,

1976, pp. 22-26), and is explained in detail in Appendix C. The remaining portion of this section summarizes the variables used in the sample size calculations and gives the minimum sample size results by trip rate type and establishment category necessary to remain within the specified error rates.

Trip Rate Summary for Sample Size Determination

The methodology employed in the sample size determination, explained in detail in Appendix C, is based on the hypothesis that the error in a trip rate due to the size of the sample selected is linearly related to the value of the trip rate-producing variable. Thus, given an allowable trip error, in terms of truck trip ends per day, and the maximum value of the rate-producing variable, a maximum error rate may be calculated. Using this maximum error rate, adjusted for the standard deviation of the sample rate, and an operating characteristic (OC) curve for a test on the mean of a normal distribution with unknown standard deviation (the test statistic is distributed as a Student's t distribution), a minimum sample size may be determined. Comparisons across various error limit values, as well as across different trip rate types, will show minimum sample size requirements for any number of situations.

A summary of the data requirements necessary for the minimum sample size determinations is shown in Table 6-23. For the minimum sample size determination by trip rate type and establishment category, the variables of prime importance are the maximum values of the rate-producing variables--maximum square footage, maximum number of

TABLE 6-23

TRIP RATE REQUIREMENTS BY ESTABLISHMENT TYPE
FOR ERROR RATE AND SAMPLE SIZE DETERMINATION

Truck Trip Rate	Establishment Type	Sample Truck Trip Rate Values	Values of Rate-Producing Variable
Truck Trip Ends Per Day Per 10,000 Square Feet of Floor Area	Wholesale	5.5[a] 8.2[b] (22)[c]	5000 Sq. Ft.[d] 424624 Sq. Ft.[e]
	Truck Terminal	36.1 26.0 (32)	2250 Sq. Ft. 116800 Sq. Ft.
	Downtown Retail	6.3 13.5 (38)	3000 Sq. Ft. 92000 Sq. Ft.
Truck Trip Ends Per Day Per 10 Employees	Wholesale	5.0 3.5 (21)	9 Employees 546 Employees
	Truck Terminal	14.0 5.8 (34)	6 Employees 99 Employees
	Downtown Retail	4.0 5.8 (37)	3 Employees 223 Employees
Truck Trip Ends Per Day Per Truck Owned	Wholesale	2.8 0.9 (21)	1 Truck 77 Trucks
	Truck Terminal	1.8 1.1 (34)	5 Trucks 179 Trucks
	Downtown Retail	2.6 3.1 (38)	1 Truck 47 Trucks

[a] mean.
[b] standard deviation.
[c] number of observations.
[d] minimum.
[e] maximum.

employees, and maximum number of trucks owned--by establishment type, and the standard deviation of the sample trip rate.

Various error limits, in terms of truck trip ends per day, were chosen ranging from plus or minus 10 to plus or minus 50 truck trip ends per day. The minimum sample sizes required to remain within each of these error ranges for each establishment and trip rate type are given in Table 6-24. Details of the determination of these minimum sample sizes are shown in Appendix C.

An examination of the minimum sample size requirements in Table 6-24 shows that large sample sizes--in excess of 100 observations in each establishment category in most cases--are required when using a truck trip rate per 10,000 square feet of floor space. Large samples are thus usually required even at the upper limits of the error rates shown--plus or minus 50 truck trip ends per day. Since the largest average number of truck trip ends per day is only 46.0 (for the truck terminals) it can be seen that even using sample sizes of over 100 may result in an error rate in excess of 100 percent of the mean value. Floorspace does not seem to be an accurate predictor of truck trip ends, therefore, unless extremely large sample sizes are involved.

Some improvement in the minimum sample size requirements are noticed when the truck trip end rates per 10 employees are examined. Although the necessary number of observations in the wholesale category remains quite large, other sample sizes, particularly in the truck terminal category, seem more realistic. Thus, for example, to estimate the number of truck trip ends per day at truck terminals to within plus or minus 20 trip ends per day, a minimum sample of approximately 80 establishments would be required.

TABLE 6-24

MINIMUM SAMPLE SIZE REQUIREMENTS BY ESTABLISHEMNT AND TRIP RATE TYPE FOR SELECTED TRIP END ERROR LIMITS

Truck Trip Rate	Establishment Type	Maximum Value of Rate Producing Variable	Minimum Number of Establishment Samples				
			±10.0 Truck Trip Ends/Day	±20.0 Truck Trip Ends/Day	±30.0 Truck Trip Ends/Day	±40.0 Truck Trip Ends/Day	±50.0 Truck Trip Ends/Day
Truck Trip Ends per Day per 10,000 Square Feet of Floor Area	Wholesale	424,624 Sq. Ft.	>100	>100	>100	>100	>100
	Truck Terminal	116,800 Sq. Ft.	>100	>100	>100	>100	>100
	Downtown Retail	92,000 Sq. Ft.	>100	>100	>100	95	60
Truck Trip Ends per Day per 10 Employees	Wholesale	546 Employees	>100	>100	>100	>100	>100
	Truck Terminal	99 Employees	>100	80	38	23	16
	Downtown Retail	223 Employees	>100	>100	>100	100	62
Truck Trip Ends per Day per Truck Owned	Wholesale	77 Trucks	>100	>100	52	32	23
	Truck Terminal	179 Trucks	>100	>100	>100	>100	>100
	Downtown Retail	47 Trucks	>100	>100	>100	>100	82

The minimum sample size requirements for truck trip end rates per truck owned are also quite large although, in this case, smaller sample sizes are required in some of the larger error limit categories of the wholesale category. Since the average number of truck trip ends at the wholesale establishments surveyed, however, is only 26.5 truck trip ends per day, well over 100 observations are still required to obtain any degree of confidence in the developed truck trip rates.

Since the minimum sample size requirements depend both on the standard deviation of the sample trip rate and the maximum value of the rate-producing variable employed in determining the truck trip rate, smaller minimum sample sizes will result from smaller standard deviations and smaller maximum values of rate-producing variables. The high requirements of wholesale establishments for both the per square feet and per employee categories are thus partly caused by an extremely large wholesale establishment with almost one-half million square feet of floor area and over 500 employees. In addition to using these high rate-producing variables in the sample size determination, these values may also significantly affect the rate's standard deviation. This problem may be alleviated somewhat through more effective stratification of establishments by establishment size in each of the major categories.

Summary

The analysis of the establishment-level truck trip generation survey has considered several elements in some detail. Aggregate

characteristics of the survey, including the temporal variation of truck trip ends at each major establishment type and the stratification of truck trip ends by truck type and trip purpose, have been considered. Truck trip rates by various rate-producing variables have been developed and regression analyses relating truck trip ends to significant independent variables have been performed. Finally, minimum sample sizes for specified truck trip end error limits for the three establishment types have been determined.

The purpose of this final section is to summarize the significant findings of each of the previously described areas relating to the establishment truck survey. Each area is considered individually below.

Aggregate Characteristics

The aggregate characteristics of the establishment-level truck trip survey included discussions of the daily and hourly variation of truck trip ends by establishment type as well as a breakdown of truck trip ends by establishment type and truck type or trip purpose.

The daily variation of truck trip ends was quite similar over a week's period of time within all three major establishment groups. Slightly lower numbers of truck trip ends were noticed at both the beginning and the end of the workweek, however, and, except for the major truck terminals, few truck trips were made on the weekend.

The hourly frequency distributions by vehicle type for each of the three major establishment groups were quite different. Wholesale establishments showed a quite diverse pattern of truck trip ends by time of day with the great majority of the movements taking place

between 5:00 a.m. and 5:00 p.m. Peak movements at wholesale establishments occurred during the hours ending at 8:00 a.m., 11:00 a.m., and 2:00 p.m.

The temporal pattern of truck trip ends at truck terminals exhibited several unique characteristics. Two very pronounced peaks occurred--at 9:00 a.m. and 4:00 p.m. Truck trips at truck terminals were being made over the entire 24-hour period, however; this is in contrast to the other establishment types. Finally, the distribution of truck trip ends at truck terminals was made up almost entirely of heavy (tractor-trailer combination) vehicles.

The final establishment category--downtown retail establishments--had almost all its truck trip movements during the normal 8:00 a.m. to 5:00 p.m. working hours. The retail establishment trips, moreover, were made up almost exclusively of those trips made by light (panel pickup and other single axle, single tire) vehicles.

Aggregate distributions by trip purpose indicated that the purpose of "deliver goods" was the single most important characteristic of the truck trip ends. Other purposes were of importance, however, particularly in selected sub-establishment categories. In the case of truck terminals, for example, "returning to base of operations" and tractors dropping off empty trailers were also important. Similarly, in the retail category, "pick up and deliver goods" was a frequently coded trip purpose.

Establishment-Level Truck Trip Rates

Truck trip rates were developed based on three independent establishment-level variables--total square feet of floorspace, total employment, and total number of establishment-owned trucks. A comparison of the developed truck trip rates by major establishment type showed significant differences in both the floorspace and employment rates between the truck terminal and wholesale establishments as well as the truck terminal and downtown retail establishments. Significantly different truck trip rates were not noted between the wholesale and downtown retail categories nor for the rates developed per establishment-owned truck. When the major establishment groups were further stratified into sub-establishment types, differences were noted between the trip rates of some sub-establishment types within a major establishment category. This was particularly true in the truck terminal category where differences in the trip rates between common carrier and local cartage operations were seen.

Establishment-level truck trip rates also varied by establishment size in some cases. When truck terminals were grouped into various size facilities as measured by both floorspace and employment, for example, significant differences in some truck trip rates between different sized groups were observed. The same may be said of some downtown retail groupings by establishment size although stratifications by both establishment size and sub-establishment type may provide more meaningful results. Sample size limitations, unfortunately, precluded this.

Significant Independent Variables in Truck Trip Rate Development

Simple linear regression and stepwise multiple regression analyses were performed to determine which single independent variable--total floorspace, total employment or total trucks owned--was the best predictor of total truck trips per day and whether the stratification of the floorspace, employment, and trucks-owned variables by type significantly improved the establishment level models. Results of the simple linear regressions indicated that total square feet of floorspace gave the best model for the wholesale category while total employment was the best single variable for use in the truck terminal category. None of the three independent variables used resulted in an acceptable model for the downtown retail establishments.

Stepwise multiple regression analyses indicated that the sequential addition of the three "total" variables to the model resulted in little added significance but that the breakdown of the total floorspace, employment, and trucks-owned variables sometimes significantly improved the trip end models. The added chore of forecasting additional independent variables and some problems with colinear variables. however, offset any advantages gained by somewhat improved statistical reliability.

Sample Sizes for Specified Error Rates

The final concern of this chapter was the determination of sample size requirements for establishment-level truck trip generation surveys necessary to remain within specified error limits in terms of truck

trip ends per day. Using a technique developed for an evaluation of automobile trip generation at special traffic generators, it was found that, because of large standard deviations in the sample dependent variables, in most cases large sample sizes (in excess of 100 establishments) were needed to remain within reasonable error limits. Reduction in the sample standard deviation of the truck trip rates, perhaps through better stratification or grouping of similar establishments or the deletion of unique observations, may improve the results of this technique.

CHAPTER 7

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS OF THE RESEARCH

The objectives of this research have been to examine the range of techniques available for use in urban truck travel demand forecasting and to investigate the use of a specific technique--an establishment-level truck trip generation survey--for forecasting urban truck movement activity, particularly of a localized nature. Application of the proposed techniques at various levels in the urban transportation planning process will enable local planning agencies, particularly in small and medium-size urban areas lacking sophisticated planning tools and large financial capabilities, to deal with a wide range of issues relating to truck travel in urban areas.

Several levels of truck travel demand forecasting have been investigated in the research. In the strategic, or long-range, planning area the traditional methods of area-wide truck travel forecasting, particularly truck trip generation analysis using multiple regression analysis, have been reviewed and summarized. In addition, the feasibility of truck trip end stratifications by truck type, trip purpose, and land use at destination has been examined for ways of improving the multiple regression models for predicting network-wide truck trip ends.

At a somewhat lower level of analysis--in terms of the sophistication required, level of detail, and time frame--an investigation of the use of truck trip end rates by general land use categories has been made. Use of the land-area truck trip rates, both those previously reported in the literature and those developed as part of this

research, may be made to evaluate the impact, in terms of truck activity, which land use decisions may have on localized areas.

Finally, the major portion of this research has been concerned with the development of establishment-level truck trip generation rates--the final level of analysis and, of course, the most detailed. Using a sample of specific establishments in several case study cities, various truck trip rates have been developed and compared, significant variables for use in the determination of truck trip rates have been identified, and minimum establishment sample sizes associated with specified truck trip end error rates have been proposed.

The major results of the analyses of each of the three levels of urban truck travel demand forecasting--long-range or area-wide, land area truck trip rate analysis, and establishment-level--are summarized in the following sections.

Summary

Trip End Stratification in Multiple Regression Analysis

The traditional trip end stratifications used in long-range truck trip generation analysis employing multiple regression analysis were expanded in this section of the research. In addition to the usual stratifications by "light" and "heavy" truck vehicles, total truck trip ends were stratified according to additional truck types, by trip purpose, and by land use at the truck trip destination. Multiple regression models were then developed for each individual truck trip end category and the results compared to the overall unstratified models. Improvements in both the statistical strength of

the models and the functional relationship of the independent variables to the stratified dependent variable were desirable.

The stratifications by additional truck types, for origin-destination data from three urban transportation studies, showed no improvements when compared to the original, unstratified equations. For the most part, the same independent variables present in the total trucks model appeared in the models for individual truck types. In addition, the statistical strength of the stratified models was often lower than that of the overall model.

Similar conclusions were reached regarding the stratification of truck trip ends by trip purpose, performed on data from two urban areas. The models developed for the stratified data, which were coded as either "service"-related or "goods"-related truck movements, once again showed that the unstratified, total truck models were more acceptable in terms of overall quality. Improvements in one of the categories of the stratified models were sometimes noted; the other category always gave a much poorer model, however, with the overall result being no improvement.

The stratifications by land use at destination, in contrast, resulted in significantly improved regression models for two of the three urban areas tested. This stratification involved grouping total truck trip ends into either one of two categories--"industrial" trip ends destined to various industrial and manufacturing land uses or "consumer"-related trip ends to land uses most closely associated with the needs of the area's population. Both in terms of the types of independent variables entering the equations and the overall strength

of the equations (as measured by the overall F value) the models stratified by land use at destination were a noticeable improvement over the overall total truck model. Intuitively, the industrial versus consumer breakdown of truck trips also makes sense; it is in many ways comparable to the basic/non-basic employment breakdown employed in economic analysis.

Land-Area Trip Rate Analysis

At a somewhat finer level of detail than the area-wide truck trip generation analysis using multiple regression analysis is the use of land area truck trip rates. In addition to their utility in evaluating the truck traffic impact of land use decisions on a local level, however, the use of truck trip rates by generalized land use type--on a per square mile or per acre basis--is also important in sketch planning decisions relating to truck travel.

This section of the research developed truck trip rates by generalized land use categories from origin-destination data for four case study cities. The overall trip rates were compared with previously developed rates as well as broken down into rates by vehicle type--light, medium, and heavy trucks.

As expected, commercial and manufacturing land uses were the greatest generators of truck trips, although tremendous variation across urban areas was noted. Only residential land uses, in fact, showed any stability over the several urban areas examined, averaging about two truck trip ends per acre of residential land. Difficulties in comparing other land use trip rates across the urban areas studied resulted from the varying land use definitions for the same general

land use type. Definitional problems were also evident in the categorization by vehicle type. A strong need for some standardization was thus evident.

Truck Trip Generation at the Establishment Level

The major portion of this research was concerned with truck trip generation at the level of the individual business establishment. This establishment-level analysis, which developed truck trip rates for various categories of establishments, is both the most disaggregate level of analysis considered in the research and the one which has the most immediate and most localized application. Use of the results of the establishment-level truck trip generation survey may be made to evaluate the environmental impact, in terms of noise pollution, for example, of a proposed truck terminal location, or to design an interchange or access roads to accommodate an industrial park with a substantial volume of heavy truck movements.

The establishment-level truck trip generation study consisted of a week long survey of a sample of establishments selected from three business establishment types--wholesale distributors, truck terminals, and downtown retail establishments. In addition to the collection of truck movement data at these establishments, establishment characteristic data such as the number of employees by type, total floorspace by function, and total establishment-owned trucks, were collected. These establishment characteristics allowed the development of establishment truck trip rates per 10,000 square feet of floor area, per 10 employees, and per establishment-owned truck. The breakdown of establishment characteristics by type and function

also enabled an analysis of the independent variables most highly related to establishment truck trip ends to be made. Finally, the use of the sample establishment trip rates allowed a determination of minimum establishment sample sizes for specified truck trip end error rates to be made.

Aggregate characteristics of the establishment-level truck trip survey pointed out differences in truck activity among the three major establishment groups. The temporal distributions of daily truck trip ends by establishment type, for example, were quite dissimilar as were the proportions of truck types and trip purposes to the various establishments. The developed truck trip rates also varied significantly between some of the paired establishment groups. Truck trip rates also showed some variation within several major establishment groups. Different types of truck terminal operations, for example, showed significantly different truck trip rates in some cases. Finally, the developed truck trip rates also showed some significant variations within major establishment groups when establishments were grouped by establishment size.

When simple regression analyses relating total truck trip ends per day by major establishment type to establishment characteristic totals were performed, satisfactory relationships between wholesale and truck terminal truck trip ends and total floorspace and total employment, respectively, were achieved. Little improvement was noted when the variables were added in a stepwise manner to a multiple regression model, however, nor when establishment characteristics by type and function were used to develop multiple regression models.

Sample size requirements for major establishment groups were shown to be quite large--in excess of 100 establishments--for accuracy within reasonable error rate limits. These requirements could be reduced through better stratification of groups by both establishment size and function.

Conclusions and Recommendations

This research has investigated techniques for addressing issues relating to urban truck activity on a number of levels. Application of the research results and recommendations for additional research activities are similarly structured to apply at various levels depending on the resources available for the investigation, the scope of the problem under study, and the time requirements for implementation. The major conclusions and recommendations for each of these levels are listed below.

1. Conclusion: The multivariate zonal regression models used in the past to estimate area-wide truck movements have often been cumbersome and difficult to interpret due to the inclusion of an excess of independent variables, the use of colinear variables, and the problems associated with forecasting several independent variables.

Recommendation: If regression analysis is to be employed in the development of long-range, area-wide truck trip generation models, efforts should be made to develop truck trip regression models which are as simple and straightforward as possible. The use of two independent variables, for example, is in most cases, the most complexity which can be attained. Additional independent variables not only often

result in problems of colinearity but necessitate additional forecasting efforts.

2. Conclusion: Although the stratification of truck trip ends for use in developing stratified zonal truck trip regression models into additional stratifications by truck type and stratifications by truck trip purpose do not seem appropriate, truck trip end stratification by the trip's destination land use may result in improved regression models, both in terms of the statistical strength of the models and the functional relationship of the individual independent variables to the specific truck trip end totals, when compared to the original unstratified models.

Recommendation: The development of individual stratified regression models for "industrial" and "consumer"-related truck trip ends should be further investigated. The need for precise definitions of what land uses constitute "industrial" and "consumer" uses is apparent, however, as is a degree of uniformity in land use categories across urban areas if any general comparisons are desired.

3. Conclusion: In the short-range, tactical planning area, the use of land area trip rate analysis, which uses simple truck trip rates per acre or per square mile of a generalized land use category, is appropriate in evaluating the truck traffic impact of land use decisions when specific establishment functions are not yet known.

Recommendation: Use land area truck trip analysis techniques when time and resources necessary for large-scale costly procedures are not available. Also consider the use of land area trip rate techniques in the solution of localized, as opposed to area-wide,

planning problems when establishment-level truck trip data are not available or appropriate. The evaluation of the truck traffic impact of a proposed industrial park where the nature of the specific establishments occupying the site may be somewhat uncertain is an example.

4. Conclusion: Because of the large variation in land area truck trip rates among the different urban areas studied, the use of "borrowed" rates, at least for the present time, seems rather risky.

Recommendation: Until data on land area truck trip rates from additional urban areas allow the development of rates with widespread applicability, land area truck trip rates developed for one's own particular area should be relied on. This development is easily accomplished if origin-destination data for the area transportation study has coded destination land use on its truck trip records.

5. Conclusion: An additional drawback to the use of average land area truck trip rates is their variability within the generalized land use categories. Commercial land uses, for example, include both wholesale and retail categories which may vary tremendously in their truck trip generating ability due to specific function, location, size, and a range of other factors.

Recommendation: A finer level of analysis is necessary, using individual business establishments, when the land use trip rate technique appears too gross for particular localized planning issues relating to urban truck traffic.

6. Conclusion: An analysis of the establishment-based truck trip survey reveals that establishment-level truck trip rates vary

both by establishment and sub-establishment category as well as by establishment size in some cases.

Recommendation: Use of the establishment-level truck trip generation results, in terms of either truck trip rates by floorspace or employment variables or through simple linear regression models, may be made to evaluate proposed short-range, localized issues relating to truck movements near major truck generators.

7. Conclusion: Care must be exercised in the use of establishment-level truck trip rates. An examination of the rates developed in this research shows wide variability across different urban areas.

Recommendation: "Borrowed" establishment rates should be used with caution until additional research in this area indicates some degree of stability across cities of various size, economic structure, and so forth.

8. Conclusion: In order to develop establishment-level truck trip generation rates which fall within certain specified error limits of the true truck generation rate at the establishment based on only a selected sample of establishments, large sample sizes may be necessary in most cases.

Recommendation: Attempt to reduce the need for larger than necessary sample sizes by grouping establishments with a particular function into similar categories based on establishment size and try to eliminate deviant (in terms of size) observations.

9. Conclusion: When establishment-level truck trip surveys are conducted with the establishments themselves collecting the necessary truck trip data, the technique is relatively inexpensive, adequately

precise, and little bother to the establishments--some of which collect most of the necessary information routinely.

Recommendation: Encourage the cooperation of business establishments in collecting or releasing information on truck movements at their establishments by convincing them of the benefits which may accrue to them, in terms of improved truck routing for example, from their assistance.

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APPENDIXES

APPENDIX A

TRUCK TRIP GENERATION

REGRESSION EQUATIONS

TABLE A-1

TRUCK TRIP GENERATION REGRESSION EQUATIONS

Urban Area and Year	Regression Equation(s)	R^2	Standard Error of Estimate / Mean	Remarks
Boston, MA 1963	Light Truck Trip Productions and Attractions = 0.0969 (Manufacturing and Other Employment) + 0.0673 (Retail, Service, Finance, Insurance & Real Estate Employment) + 0.1130 (Population)	-	-	Light truck = All 2 axle, 4 wheel commercial vehicles.
	Heavy Truck Trip Productions and Attractions = 0.1182 (Manufacturing and Other Employment) + 0.0276 (Retail, Service, Finance, Insurance & Real Estate Employment) + 0.0574 (Population)	-	-	Heavy truck = All other commercial vehicles. P's and A's estimated by same equations; no unique zones.
Lake Charles, LA 1964	Total Internal Truck Productions or Attractions = 4.54 ± 5.22 (Commercial Acreage) + 3.10×10^{-5} (Retail Sales) + 0.27 (Total Dwelling Units)	0.81	51.4%	Commercial acreage includes trade plus SLU codes 61-65.
	External Truck Attractions = 12.2 + 11.81 (Industrial Acreage) + 0.02 (Total Employment)	0.60	86.6%	

TABLE A-1 (continued)

Urban Area and Year	Regression Equation(s)	R^2	Standard Error of Estimate / Mean	Remarks
Winston-Salem, NC 1965	Light Trucks = 0.09 (Population + 0.24 (Dwelling Units) + 0.12 (Employment-White Collar) + 0.06 (Employment-Blue Collar) - 0.24 (School Enrollment) + 0.02 (Retail Sales-Convenience) + 16.22	0.62	61.0%	Truck equations apply to both attraction and production trip ends.
	Heavy Trucks = 0.04 (Population + 0.07 (Dwelling Units) - 0.16 (Cars) + 0.19 (Labor Force-White Collar) + 0.18 (Employment-Blue Collar) - 0.08 (School Enrollment) + 13.30	0.40	132.0%	
	External Trucks = 0.75 (Cars) - 0.57 (Labor Force-Blue Collar) + 0.86 (Employment-White Collar) + 0.82 (Employment-Blue Collar) - 0.18 (School Enrollment) + 0.02 (Retail Sales-Convenience) + 0.05 (Retail Sales-General) - 1.97	0.72	74.0%	External equation applies to attraction trip ends.
Phoenix, AZ 1967	Light Truck Productions = - 6.25 + 2.4084 (Living Units)$^{0.75}$ + 0.2458 (Employment)	-	-	
	Heavy Truck Productions = 10.95 + 1.5161 (Living Units)$^{0.75}$ + 0.1067 (Employment)	-	-	

TABLE A-1 (continued)

Urban Area and Year	Regression Equation(s)	R^2	Standard Error of Estimate / Mean	Remarks
	Light Truck Attractions = - 0.93 + 2.3438 (Living Units)$^{0.75}$ + 0.2476 (Employment)	-	-	
	Heavy Truck Attractions = 4.98 + 1.5302 (Living Units)$^{0.75}$ + 0.1054 (Employment)	-	-	
Savannah, GA 1967	Truck & Taxi Productions & Attractions = 0.013 (Office Space Floor Area) + 2.168 (Manufacturing Acreage) + 0.691 (Households) + 0.056 (Retail Floor Space)$^{0.8}$ + 515	0.74	33.0%	
Louisville, KY 1967	Truck Productions or Attractions = 147.4 + 0.1145 (Population) + 0.1358 (Total Employment)	0.81	37.0%	
Columbia, MO 1967	Pickup Truck Trip Ends = 0.55784 (Retail Employment) + 0.42268 (Resident Dwelling Units) + 0.09730 (Total Employment) + 0.12324 (Office Floor Area) + 32.86913	0.48	72.0%	
	Heavy Truck Trip Ends = 0.19521 (Storage Floor Area) + 0.26053 (Total Employment) + 0.47708 (Resident Value Ownership) + 117.10520	0.32	83.0%	

TABLE A-1 (continued)

Urban Area and Year	Regression Equation(s)	R^2	Standard Error of Estimate / Mean	Remarks
	External Non-Resident Truck Trip Ends = 0.011896 (Total Floor Area) + 7.844296	0.24	159.0%	
	External Resident Truck Trip Ends = 0.024997 (Storage Floor Area) + 6.845389	0.27	184%	
Kansas City, MO 1967	Total Truck Trip Ends = 7 + 0.23304 (Non-Home Auto Trip Ends - Work Purpose) + 0.12073 (Total Auto Trip Ends)	0.75	52.0%	Preferred to alternate method which considered 2 equations - residential zones and unique zones. Although pooled SEE/$\bar{Y}$ for alternate was lower it was felt that there would be forecasting difficulties with unique zones.
Montgomery, AL 1968	Internal Truck Productions = 144 + 0.74 (Dwelling Units) + 0.64 (Employment)	0.76	32.0%	Zones with < 100 trip ends not considered.
	Internal Truck Attractions = 209 + 0.52 (Dwelling Units) + 0.45 (Employment)	0.53	50.0%	

TABLE A-1 (continued)

Urban Area and Year	Regression Equation(s)	R^2	Standard Error of Estimate / Mean	Remarks
Cedar Rapids, IA 1968	Truck Productions and Attractions = - 15.4 + 1.59 (Total Dwelling Units) + 1.50 (Retail Employment) + 0.0007 (Warehousing, Truck Terminals, Sq. Ft.)	0.85	41%	
	Truck IE & EI Combined = 33.4 + 0.00005 (Total Retail Floor Space in Sq. Ft.) + 0.00007 (Warehousing, Truck Terminals, Sq. Ft.) + 0.0123 (Employment)	0.70	36%	
Anchorage, AK 1969	Truck and Taxi Productions or Attractions = 7.687 + 0.699 (Total Employment) + 1.432 (Dwelling Units) + 0.642 (Commercial Acres) + 3.263 (Residential Acres)	0.82	45%	
Detroit, MI 1969	Truck Productions and Attractions = 143.21 + 0.06 (Manufacturing - Transportation Equipment Employment) + 0.25 (Manufacturing - Other Employment) + 0.54 (Transportation, Communications & Utilities Employment) + 0.43 (Wholesale & Retail Employment) + 0.84 (Business and Repair Service Employment) + 0.11 (Total Population)	0.48	66%	

TABLE A-1 (continued)

Urban Area and Year	Regression Equation(s)	R^2	Standard Error of Estimate / Mean	Remarks
Kalamazoo, MI 1969	District Truck Productions or Attractions = - 45 + 0.059 (Population) + 0.17 (Total Employment)	0.77	60%	
Harrisburg, PA 1969	Total Truck Trips Produced and Attracted = 0.76016 (Dwelling Units) + 0.25553 (Industrial Employment) + 0.79154 (Retail Employment) + 59.94371	0.62	59%	
Spartanburg, SC 1969	Truck-Taxi Productions and Attractions = 0.42 (Dwelling Units) + 0.10 (Employment) + 0.03 (Retail Sales in $1000) + 32.35	0.48	68%	
Huntsville, AL 1970	Truck and Taxi Productions = 19.7 + 0.009 (Convenience Retail Floor Area) + 0.75 (Population) + 0.136 (Blue Collar Employment)	0.76	54%	
	Truck and Taxi Attractions = 20.2 + 0.009 (Convenience Retail Floor Area) + 0.075 (Population) + 0.140 (Blue Collar Employment)	0.76	54%	

TABLE A-1 (continued)

Urban Area and Year	Regression Equation(s)	R^2	Standard Error of Estimate / Mean	Remarks
Ogden, UT 1970	Commercial Productions = 48 + 0.2840 (Employment) + 0.4811 (Dwelling Units) + 0.0812 (Commercial Floor Area) + 3.1483 (Industrial Acreage)	0.77	43%	
	Commercial Attractions = 47 + 0.2697 (Employment) + 0.4723 (Dwelling Units) + 0.0850 (Commercial Floor Area) + 2.7163 (Industrial Acreage)	0.79	42%	
Salt Lake City, UT 1970	Commercial Productions = 79.6945 + 0.353512 (Employment) + 2.82971 (Residential Acreage) + 4.73022 (Commercial Acreage)	0.59	61%	
	Commercial Attractions = 109.353 + 0.395996 (Employment) + 2.854 (Residential Acreage)	0.58	61%	
Birmingham, AL 1971	Truck and Taxi Productions or Attractions* = 135.82285 (Retail Sales Acreage)$^{0.5}$ + 0.26509 (Total Employment) + 0.44612 (Dwelling Units)	-	-	*For all zones with total employment $\geq$ 100 or dwelling units $\geq$ 100.

TABLE A-1 (continued)

Urban Area and Year	Regression Equation(s)	R^2	Standard Error of Estimate / Mean	Remarks
	Truck and Taxi Productions or Attractions** = 97.36842 + 14.93158 (Agriculture - Mining Employment) + 8.17063 (Wholesale - Distribution Acreage)	-	-	**All other zones.
Atlantic City, NJ 1971	"On-Shore" Truck Productions = 49.54 + 0.25 (Total Employment)	0.68	-	"On-Shore" = mainland;
	"Off-Shore" Truck Productions = 160.68 + 0.21 (Total Employment)	0.52	-	"Off-Shore" = island groupings.
	"Core City" Truck Productions = 244.90 + 0.19 (Total Employment)	0.62	-	"Core City" = all off-shore zones which included unusual trip generators and/or transportation facilities.
	"On-Shore" Truck Attractions = 53.58 + 0.25 (Total Employment)	0.65	-	
	"Off-Shore" Truck Attractions = 158.98 + 0.22 (Total Employment)	0.53	-	
	"Core City" Truck Attractions = 241.43 + 0.19 (Total Employment)	0.62	-	
La Crosse, WI 1971	Truck and Taxi Productions and Attractions = 97.7 + 0.599 (Total Employment Force) + 0.707 (Number of Dwelling Units)	0.56	55%	

TABLE A-1 (continued)

Urban Area and Year	Regression Equation(s)	R^2	Standard Error of Estimate / Mean	Remarks
Pittsburgh, PA 1972	Light Truck Trip Productions or Attractions = 29.74236 + 0.22473 (Number of Housing Units) + 1.08811 (Wholesale Employment) + 0.15800 (Retail Trade Employment)	0.35	86%	Light trucks = pickup or panel trucks. Medium trucks = two axle single or dual tire vehicles and three or more axle single unit vehicles. Heavy trucks = semi-trailers and full trailers.
	Medium Truck Trip Productions or Attractions per Developed Acre = 0.14857 + 0.26138 (Utilities, Communication, and Transportation Employment/Developed Acre) + 3.09890 (Non-residential Acres/ Total Acres)	0.71	148%	
	Heavy Truck Trips per Developed Acre = 0.00434 + 0.01786 (Manufacturing Employment/Developed Acre) + 0.55870 (Non-residential Acres/Total Acres)	0.41	267%	
Colorado Springs, CO 1973	Heavy Truck Productions = 13.54 + 0.160 (Dwelling Units) + 2.011 (Garaged Trucks) + 0.076 (Total Employment)	0.43	115%	Heavy trucks = all trucks other than pickups. Heavy truck attractions = Heavy truck productions + external-local truck attractions.
	Heavy Truck Attractions = 14.33 + 0.162 (Dwelling Units) + 2.731 (Garaged Trucks) + 0.085 (Total Employment)	0.47	110%	

TABLE A-1 (continued)

Urban Area and Year	Regression Equation(s)	R^2	Standard Error of Estimate / Mean	Remarks
Tuscaloosa, AL 1974	Truck Productions & Attractions = 95 + 0.7466 (Autos) + 0.0016 (Retail Floor Area)	0.67	54%	
Pueblo, CO 1974	Truck Productions and Attractions = 1.48 (Total Employment)	0.49	87%	
Indianapolis, IN 1974	Heavy Truck Trip Ends = 101.865 + 0.070 (Total Employment) + 0.719 (Wholesale Employment) + 1.097 (Trucks) + 0.187 (Transportation, Communication, Utilities Employment)	0.48	79%	
	Light Truck and Taxi Trip Ends = 206.040 + 0.235 (Total Employment) + 0.729 (Total Housing)	0.48	62%	
Terre Haute, IN 1974	Truck Productions = 27.46989 + 0.29883 (Persons Employed) + 0.10641 (Total Employment)	0.63	76%	Zones with zero trips excluded from analysis.
	Truck Attractions = 34.73676 + 0.25259 (Persons Employed) + 0.11806 (Total Employment)	0.71	59%	

TABLE A-1 (continued)

Urban Area and Year	Regression Equation(s)	R^2	Standard Error of Estimate / Mean	Remarks
Richmond, VA 1974	Truck Productions or Attractions = 43.84 + 0.180 (Internal Employment) + 0.370 (Dwelling Units)	0.59	46%	

Source: Urban Area Reports, Office of Highway Planning, Urban Planning Division, United States Department of Transportation, Washington.

APPENDIX B

ESTABLISHMENT QUESTIONNAIRE

SURVEY FORMS

Company Name

Street Address

City State

GOODS - VEHICLE MOVEMENT SURVEY

SECTION I - ESTABLISHMENT INFORMATION

Instructions - Complete the four questions below for your particular establishment. The information is requested only for your operations at the address listed at the top of this page. If a particular category does not apply, indicate by placing N/A in the appropriate space. Schematics of the truck type descriptions in question three are shown on page 4 of this section. Any comments you may have about truck or goods movement related problems may be recorded on page 3.

1. What is your firm's total square feet of floor area at the above location for each of the following functions?

Function	Square Feet
(a) Production	_____
(b) Sales	_____
(c) Storage	
(1) Indoor	_____
(2) Outdoor	_____
(3) Total	_____
(d) Offices	_____

(e) Other (specify) ( )_____

(f) Total _____

2. What is your firm's total employment at the above location for each of the following functions?

Function	Employment
(a) Production	_____
(b) Sales	_____
(c) Clerical, Office	_____
(d) Management, Supervisory	_____
(e) Maintenance	_____
(f) Other (specify) ( )	_____
(g) Total	_____

3. How many of each of the following truck types owned or leased by the firm use the above location as a normal base of operations? (See page 4 for schematics of the truck type descriptions.)

Truck Type	Number at this Location
(a) Panel or Pickup Trucks	_____
(b) Other Single Unit, Single Rear Tire Trucks	_____
(c) Single Unit, Dual Rear Tire Trucks	_____
(d) Single Unit, 3 and 4 Axle Trucks	_____
(e) Small Truck Tractor, Semi-Trailer Combination (27' or Smaller Trailer)	_____
(f) Over-the Road Truck Tractor, Semi-Trailer Combination (Larger than 27' Trailer)	_____

4. WHOLESALERS AND DOWNTOWN RETAILERS ONLY:

   a. Does your establishment have rail access at this location?

   _____ Yes _____ No

   b. If yes, how many rail shipments do you normally receive in a week?

   _____ Approximate Number of Carloads

5. Comments:

_____

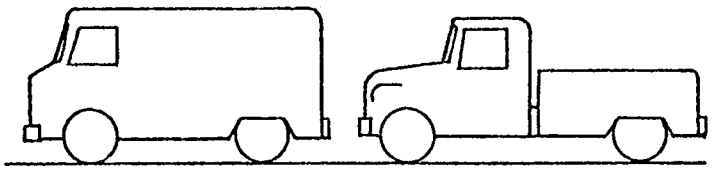
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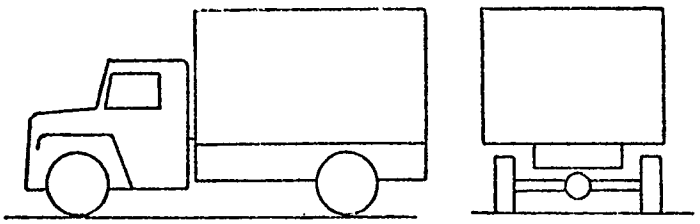
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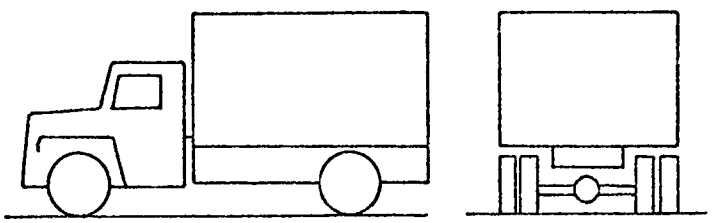
1. Panel, Pickup



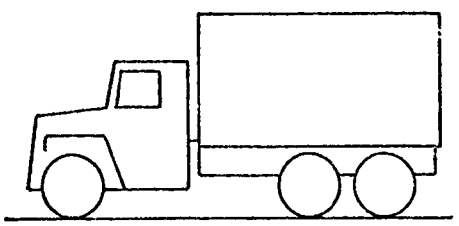
2. Single unit single rear tire



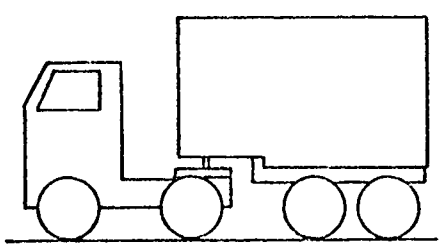
3. Single unit - dual rear tire



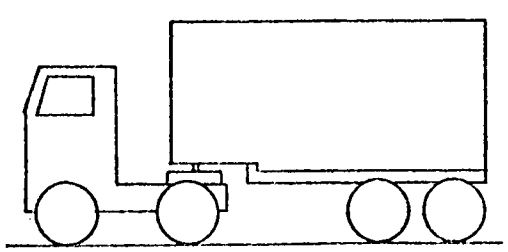
4. Single unit - 3 and 4 axle



5. Small truck tractor, semi-trailer combination (27' or smaller trailer)



6. Over-the-road truck tractor, semi-trailer combination (larger than 27' trailer)



GOODS - VEHICLE MOVEMENT SURVEY

SECTION II - TRUCK TRIP LOG

Instructions - Information in columns 1 through 9 is to be recorded for each truck trip to or from the establishment beginning at 12:01 A.M. on Sunday, _____ and ending at 12:00 Midnight on Saturday _____. A trip is defined as a one-way movement. Thus, a firm's delivery vehicle would make one trip when it leaves the establishment and another when it returns to the establishment. Each movement would be an individual trip and would be recorded on a separate line. The only exception to the above rule applies to trucks making deliveries to the establishment; only the inbound trip need be recorded in this case.

Sufficient log forms are provided for each of the seven survey days. The first form is an example of a typical log. The following specific instructions apply to the individual columns on the survey form.

Column	Information Needed
(1)	Month/Date/Year
(2)	Consecutive, for each day, starting with 1.
(3)	If the trip is coming to the establishment, check this box.
(4)	Record arrival time of trip checked in (3) and circle either A.M. or P.M.
(5)	If the trip is leaving from the establishment, check this box.

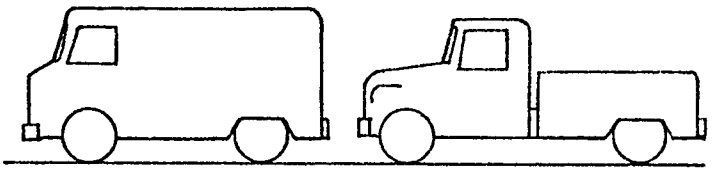
(6) Record departure time of trip checked in (5) and circle either A.M. or P.M.

(7) Record appropriate truck ownership code (items (1) through (5) directly below column (7)).

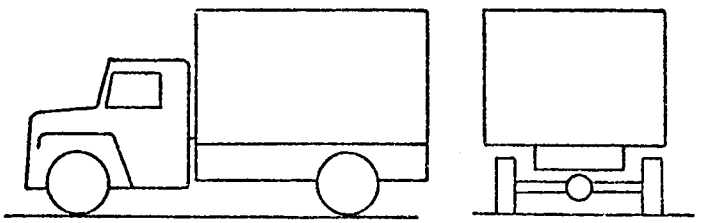
(8) Record appropriate truck type (items (1) through (6) directly below column (8); refer to schematic on page A-4 for pictures of truck types)).

(9) Record appropriate truck trip purpose (item (1) through (7) directly below column (9)).

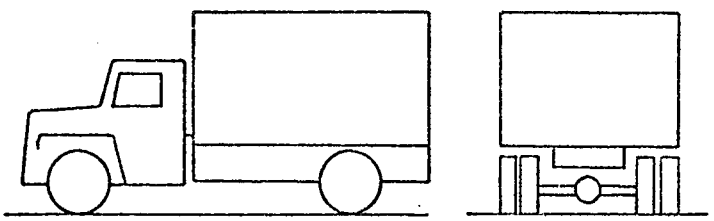
1. Panel, Pickup



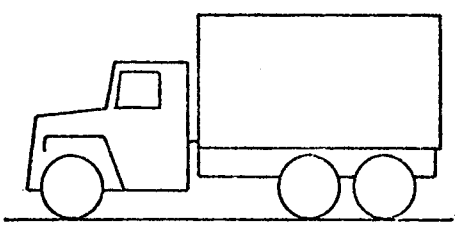
2. Single unit single rear tire



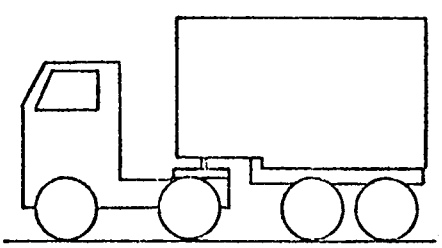
3. Single unit - dual rear tire



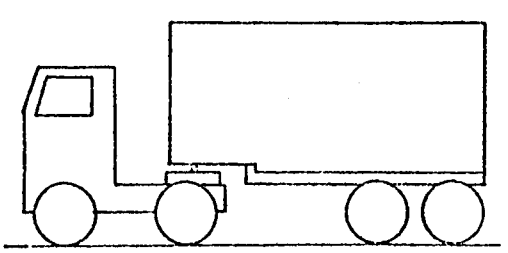
4. Single unit - 3 and 4 axle



5. Small truck tractor, semi-trailer combination (27' or smaller trailer)



6. Over-the-road truck tractor, semi-trailer combination (larger than 27' trailer)



SECTION II - TRUCK TRIP LOG

(1) Date	(2) Truck Trip Number	(3) Inbound Trip?	(4) Time of Arrival	(5) Outbound Trip?	(6) Time of Departure	(7) Truck Ownership	(8) Truck Type	(9) Trip Purpose
2/9/76	1	✓	7:20 am pm		am pm	2	2	2
2/9/76	2		am pm	✓	1:20 am pm	1	1	2
2/9/76	3		am pm	✓	2:45 am pm	1	2	3
2/9/76	4	✓	am 4:45 pm		am pm	3	5	2
2/10/76	1	✓	8:15 am pm		am pm	3	5	2
2/10/76	2		am pm	✓	11:45 am pm	1	3	1

1. Owned by your establishment.
2. Owned by supplier to your establishment.
3. Common Carrier
4. United Parcel Service (UPS)
5. Other Carrier

1. Panel, pickup
2. Other single unit, single rear tire
3. Single unit dual rear tire
4. Single unit 3 & axle
5. Small tractor trailer comb. (27' or less)
6. Over-the-road tractor-trailer comb. (larger than 27')

1. Pick up goods
2. Deliver goods
3. Pick up and deliver
4. Service call
5. Personal business
6. Base of Operations
7. Other (specify)

Firm - _____

SIC code - _____

Address - _____

City - _____ State - _____

APPENDIX C

METHODOLOGY FOR DETERMINING SAMPLE SIZE REQUIREMENTS FOR SPECIFIED TRUCK TRIP END ERROR RATES

The methodology used for determining sample size requirements for given values of rate-producing independent variables and specified truck trip end error limits was developed by Neumann and Deshpande for use in a study of automobile trip rates at special traffic generators in West Virginia (1976, pp. 22-26). The purpose of that study, as in this one, is to enable the number of trip ends at a specific establishment type to be estimated from a trip rate (per some value of an independent variable) based on a limited number of establishment observations. The specified error limits (in terms of plus or minus some number of trip ends per day) are chosen to relate to incremental volumes necessary for operational planning and design purposes. In the West Virginia study, for example, a value of ±2000 vehicles per day is deemed sufficient to justify an additional highway lane. Unless the sample of establishments surveyed allows the total daily trips to be estimated within ±2000 vehicles per day, then the procedure is of no value.

The methodology followed in the present study is patterned after that developed in the West Virginia study and is as follows:

Truck trip rates for different establishment categories may be developed using the following variables:

$TTED_i$ = actual number of truck trip ends per day at establishment i,

n = number of establishments in an establishment category,

V_{RP_i} = value of the rate producing variestablishment i (square footage, number of employees, number of trucks owned).

The truck trip rate for establishment i is then:

$$TR_i = \frac{TTED_i}{V_{RP_i}} \qquad (1)$$

and the average truck trip end rate for an establishment category (wholesale distributors, truck terminals, or downtown retail establishments) is:

$$S_E = \frac{\sum_{i=1}^{n} TR_i}{n} \qquad (2)$$

As pointed out by Neumann and Deshpande, however, trip rates at individual establishments may vary from the average rate due to several causes, including establishment size. The error associated with the average rate based on the sample number of establishment observations, as compared to the true rate if all establishments in a particular establishment category are surveyed, may also vary but this error may be reduced by increasing the number of observations in the establishment sample. Thus, given a maximum allowable error (in terms of truck trip ends per day), a minimum sample size necessary to remain within the specified error limits may be determined as follows:

Assuming that any error due to explainable causes such as establishment size and dissimilar establishment types has been accounted for in the selection of the establishment categories, then the trip end error estimate is:

$$E_{TE_i} = \pm(TTED_i - TTED_i') \qquad (3)$$

where:

E_{TE_i} = trip end error estimate for establishment i,

$TTED_i$ = actual number of truck trip ends per day at establishment i,

$TTED_i'$ = estimated (from trip rate) number of truck trip ends per day at establishment i.

This trip end error estimate, however, is also equal to the sum of the errors due to an estimate of the true rate by the sample rate plus any unexplained variation. Thus

$$(TTED_i - TTED_i') = \pm(E_R - E_{ui}) \qquad (4)$$

where $TTED_i$ and $TTED_i'$ are as before and

E_R = the error due to the use of a sample rate (S_E) due to the size of the sample and

E_{ui} = unexplained error at establishment i.

Thus,

$$TTED_i = TTED_i' \pm(E_R - E_{ui}). \qquad (5)$$

But, the errorless trip rate (P_E) equals the true number of truck trip ends divided by the rate-producing variable plus any unexplained error

$$P_E = \frac{TTED_i}{V_{RP_i}} \pm E_{ui} \quad (6)$$

or,

$$TTED_i = P_E\ (V_{RP_i}) \pm E_{ui} \quad (7)$$

Substituting equation (7) into equation (5) therefore:

$$P_E\ (V_{RP_i}) \pm E_{ui} = S_E\ (V_{RP_i}) \pm (E_R - E_{ui}) \quad (8)$$

or,

$$\pm E_R = (P_E - S_E)\ V_{RP}$$

Thus, it can be seen that the error due to the use of a truck trip rate based on a sample of observations is linearly related to the value of the rate-producing variable. This relationship is plotted in Figure C-1 which may be used to determine an error rate

$$\left| \frac{\pm E_R}{V_{RP}} \right|$$

given values for allowable truck trip end error and the rate-producing variable.

Given the maximum allowable error in the trip rate due to sample size restrictions from Figure C-1 ($S_E - P_E$), the operating characteristic curves for the test of the mean of a normal distribution with unknown standard deviation may be used to estimate minimum allowable

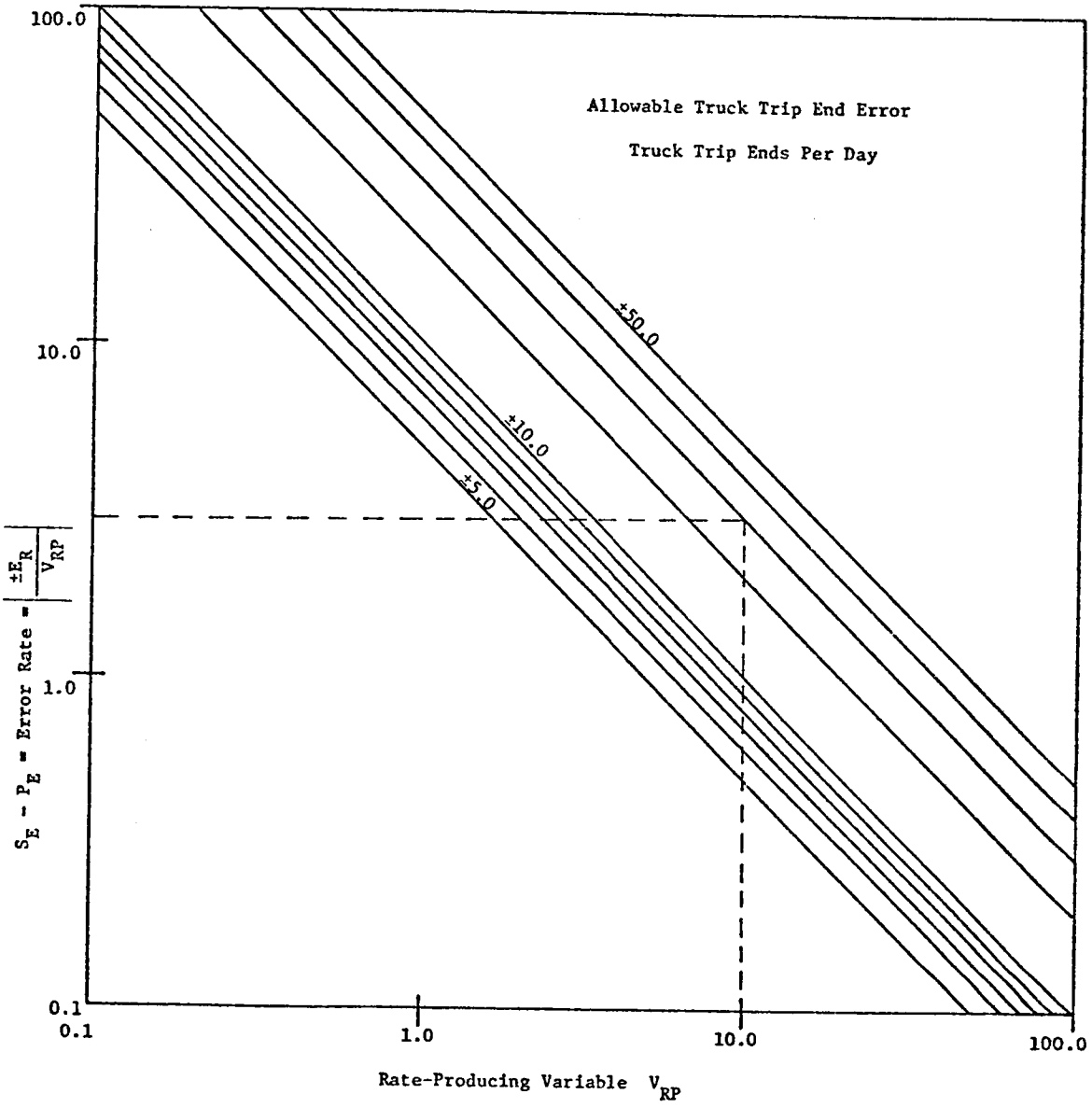


FIGURE C-1

ERROR RATES DUE TO SAMPLE SIZE
AS A FUNCTION OF THE RATE-PRODUCING VARIABLE

sample size requirements. A series of these curves, which give required sample sizes for given values of α (Type I error) and β (Type II error) and for various values of Δ ($\mu_1-\mu_o/\sigma$) are shown in Figure C-2. Transposing the axes so that, given values for α, β, and Δ, a sample size may be read directly on the vertical axis, results in the set of curves shown in Figure C-3.

Figures C-3 and C-1 are used to determine the minimum sample size requirements as follows:

For an establishment group with a maximum of 100 employees, for example, a maximum error rate ($S_E - P_E$) of 3.3 trip ends per 10 employees is obtained from Figure C-1. If the standard deviation of the truck trip rate per 10 employees, is say, 5.8, and if it can be assumed that the standard deviation of the sample rate (S) is equal to the population standard deviation (σ) an estimate of Δ may be made:

$$\Delta = \mu-\mu_o/\sigma = 3.3/5.8 = 0.57$$

For an α value of 0.05, then, and a β value of 0.10, Figure C-3 may be used to determine the minimum sample size of approximately 32.

If the sample standard deviation (S) cannot be assumed to equal the population standard deviation (σ), then the minimum sample sizes will be larger than that described above. Since this may usually be the case, it may be necessary to increase the minimum sample sizes obtained to account for the inequality.

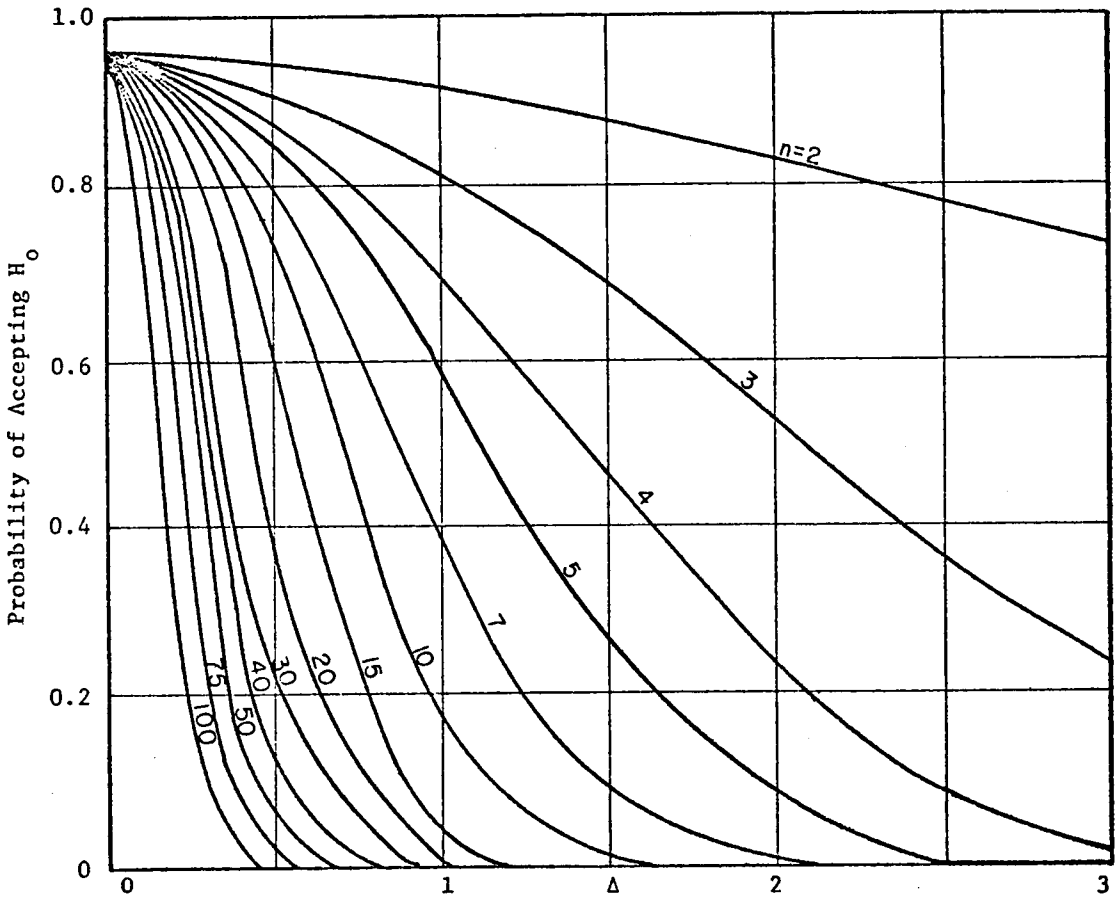


FIGURE C-2

OC CURVES FOR DIFFERENT VALUES OF n FOR THE TWO-SIDED T-TEST FOR A LEVEL OF SIGNIFICANCE $\alpha = 0.05$

Source: William H. Beyer (ed.). Handbook of Tables for Probability and Statistics. 2nd ed. Cleveland: The Chemical Rubber Co., 1968, p. 291.

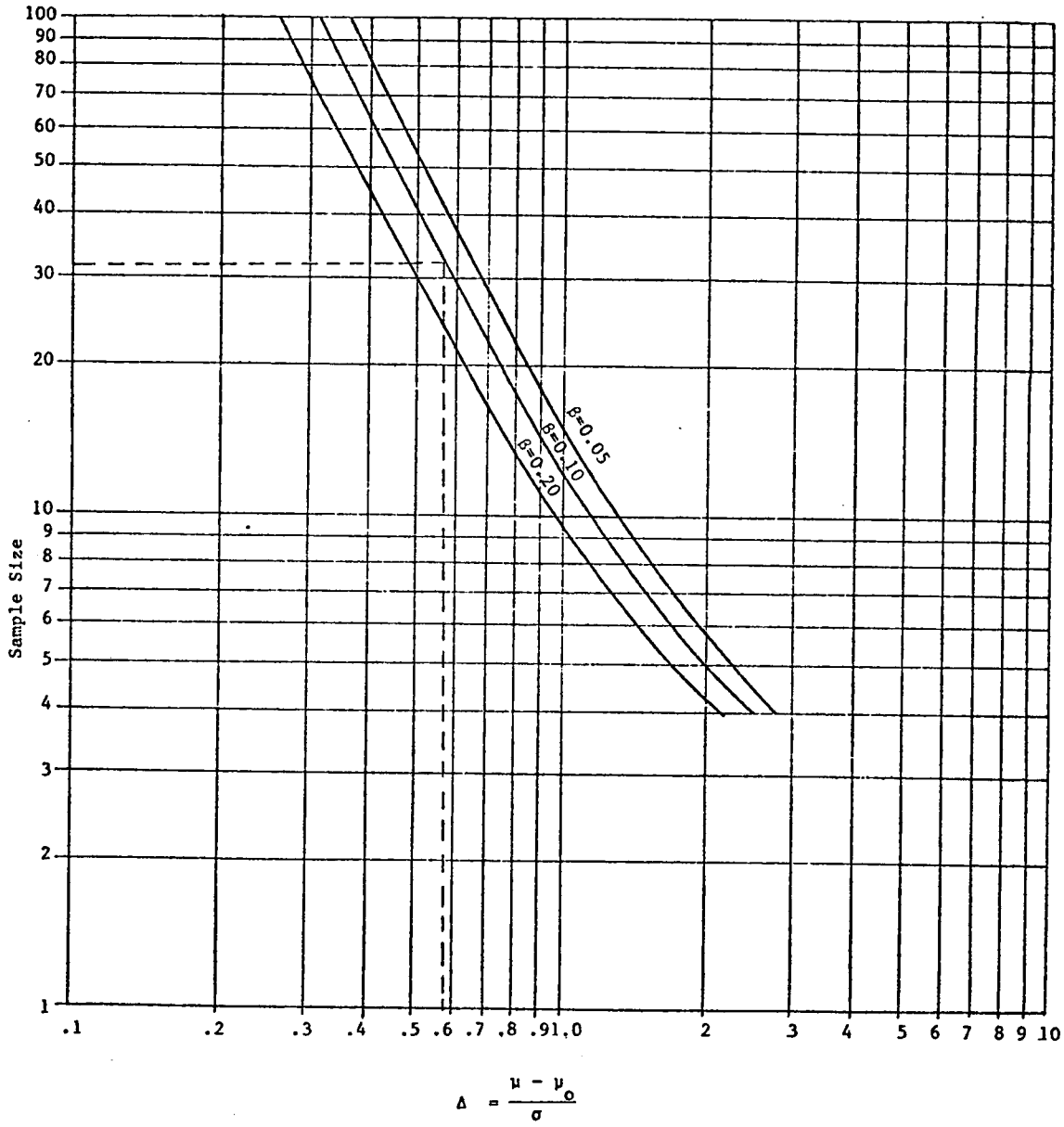


FIGURE C-3

MINIMUM SAMPLE SIZE REQUIREMENTS
FOR $\alpha = 0.05$ AND VARIOUS β VALUES GIVEN Δ

VITA

James Denis Brogan was born in Hazleton, Pennsylvania on October 24, 1945. He attended elementary school in Freeland, Pennsylvania and was graduated from St. Ann's High School in June 1963. In September 1963, he entered Villanova University, and in May 1967, received a Bachelor of Engineering degree with a major in Civil Engineering.

Following a two-year work period with Bethlehem Steel Corporation and a two-year tour of duty with the United States Army, Mr. Brogan entered the Graduate School of Purdue University, Lafayette, Indiana, in September 1971. He received the Master of Science in Civil Engineering from Purdue in May 1973. Mr. Brogan then enrolled in the Graduate School of The University of Tennessee, Knoxville, in June 1973. He received the Doctor of Philosophy degree with a major in Civil Engineering in June 1977.

Mr. Brogan is married to the former Katherine Doherty of Saugus, Massachusetts. They have two sons.