THE RELATIONSHIP OF TRAFFIC ATTRACTED TO ZONES IN A CITY'S CENTRAL BUSINESS DISTRICT TO INTRAZONAL FLOOR SPACE USE

BY

PAUL H. WRIGHT

PROJECT A-704

Technical Development and Research Project

Performed for

The Institute of Traffic Engineers

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, 1963 - 64

CONTENTS

Progress Report No. 1.

June 1963--August 1963.

Final Report.

June 1, 1963--May 31, 1964.

70-1

Project A-704

THE RELATIONSHIPS OF TRAFFIC ATTRACTED TO ZONES IN A CITY'S CENTRAL BUSINESS DISTRICT TO INTRAZONAL FLOOR SPACE USE

Progress Report No. 1

for period

June 1963 through August 1963

THE RELATIONSHIPS OF TRAFFIC ATTRACTED TO ZONES IN A CITY'S CENTRAL BUSINESS DISTRICT TO INTRAZONAL FLOOR SPACE USE

Progress Report

A grant was recently awarded by the Institute of Traffic Engineers to the Georgia Tech Engineering Experiment Station to study the relationships of traffic attracted to the central business district to CBD floor space use. Preliminary findings of the study are briefly described in the following paragraphs.

1. Total trips attracted to the CBD are most closely related to retail sales, office, and service floor space use. In the Gainesville study, public floor space use also appeared to be a strong attractor of trips. (Gainesville is the county seat of Hall County, Georgia and is an important center of government activities)

2. The attractiveness of the CBD to total person-destinations appears to be closely related to city population, the greatest relative attraction being shown by small cities. Total person-destinations in Gainesville and Chattanooga have been related to the following classifications of floor space use: Retail; Service-office; and Manufacturing-Warehousing. Since these same floor space groupings were used by Harper and Edwards (Highway Research Board Bul. No. 253) in their study of large cities, these results were comparable to the findings of Harper and Edwards. Preliminary results indicate that in this type of model, retail and service-office regression coefficients are roughly exponentially related to city population for cities

up to about one million population. This is consistent with the results of previous studies which have shown the CBD in small cities to be a relatively more important attractor of traffic than in large cities. The manufacturing-warehousing coefficient is not strongly related to city population, and in most cases has not been statistically significant.

3. As expected, shopping trips were closely related to retail sales floor space use. Reasonably good shopping trip models have been developed using various combinations of retail sales, service, office, and public floor space use. Attempts have also been made to fit non-linear curves relating shopping trips and retail sales floor space use.

In certain of the Gainesville zones, observed traffic values varied widely from those predicted by the least squares model. The apparent reason for this wide variation is that certain of the Gainesville O-D zones have large floor space areas devoted to convenience goods which have relatively small attraction to CBD shopping trips. The following second degree equation closely fits the observed data for the Chattanooga study:

$$\text{Shopping (vehicle) trips} = 0.00246X_s^2 + 1.984X_s + 52,$$

where X_s = Retail sales floor space use, thousands of square feet.

4. Reasonably satisfactory models have been developed relating work trips and retail sales, service, office, and public floor space use. Curiously, manufacturing floor space use has not been shown to be a significant attractor of work trips. This is evidently due to the fact that the CBD is not usually an important manufacturing center.

5. Predictive models have also been developed relating business trips and retail sales, service, office, and public floor space use. The classifications of floor space use reported in the floor space surveys do not appear to be strong attractors of social and recreation trips.

Greatest difficulty experienced thus far in the study has been the problem of obtaining traffic and floor space tabulations in the desired form. The Atlanta traffic data has not yet become available, but is expected soon. It is possible that suitable traffic and floor space data will be obtained from Kansas City, Missouri. Neither the Pittsburgh nor the Chicago data appears to be usable because of the small number of CBD zones.

FINAL REPORT

PROJECT A-704

THE RELATIONSHIP OF TRAFFIC ATTRACTED TO ZONES IN A CITY'S CENTRAL BUSINESS DISTRICT TO INTRAZONAL FLOOR SPACE USE

PAUL H. WRIGHT

Technical Development and Research Project
Performed for
The Institute of Traffic Engineers

1964

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station
Atlanta, Georgia

FINAL REPORT

PROJECT A-704

THE RELATIONSHIP OF TRAFFIC ATTRACTED TO ZONES IN A CITY'S CENTRAL BUSINESS DISTRICT TO INTRAZONAL FLOOR SPACE USE

By

Paul H. Wright

Technical Development and Research Project

for the

Institute of Traffic Engineers

June, 1964

Covering the Period

June 1, 1963 through May 31, 1964

ACKNOWLEDGEMENTS

Words of acknowledgement and appreciation are due those who offered guidance and assistance to the writer of this thesis.

The writer appreciates the financial assistance of the Institute of Traffic Engineers, sponsors of the research.

The writer is particularly indebted to Dr. Donald O. Covault, Thesis Advisor, and to the other members of the Thesis Advisory Committee: Professor Malcolm G. Little, Jr. and Dr. Harrison M. Wadsworth.

Personnel of the several State Highway Departments, City Planning Departments, and others were very cooperative in providing the necessary traffic and floor space data. The writer wishes to express thanks to: Messrs. Emory Parrish and David Kennison of the Georgia State Highway Department; Mr. C. S. Harmon, Tennessee State Highway Department; Mr. Charles Cunningham, Gainesville-Hall County Planning Commission; Mr. Robert Kochanowski, Director, Pittsburgh Area Transportation Study; Mr. Robert Shepard, Chattanooga Department of Planning; Mr. Kirk Kynoch, Service Bureau Corporation; Mr. Alan Welty, Hammer and Company; and Messrs. Herman Hoose and J. B. Fennel, Traffic Engineer and Finance Director, respectively, city of Charlotte, North Carolina. Other individuals too numerous to mention by name contributed technical reports and data which for one reason or another could not be incorporated into the study. Their interest and willingness to help are nevertheless appreciated.

The writer also wishes to acknowledge the assistance of the Georgia Tech Engineering Experiment Station. In particular, thanks are extended to Professors William Hines and Lynwood A. Johnson who offered advice concerning the use of the electronic computer.

Finally, the writer gratefully acknowledges the help of Mr. B. C. S. Harper and Professor H. M. Edwards whose 1960 report paved the way for this thesis. Both Mr. Harper and Professor Edwards by correspondence offered encouragement and assistance, for which the writer is very grateful.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	ii
LIST OF TABLES	vi
LIST OF FIGURES	vii
GLOSSARY	viii
SUMMARY	ix
Chapter	
I. INTRODUCTION	1
II. THE CHARACTER OF THE CENTRAL BUSINESS DISTRICT	3
Delimitation of the CBD The Size of the CBD and Its Influence on Traffic Flow The CBD in Transition The Future of the CBD	
III. THE PREDICTION OF TRAFFIC FLOW TO THE CBD	15
The Fratar Method Gravity Models Floor Space Models	
IV. METHOD OF STUDY	19
Linear Regression Statistical Measures of Correlation and Regression Measures of Importance of the Regression Model Measures of Importance of the Individual Variables	
V. RESULTS	29
Total Traffic Models Total Traffic Models for Gainesville, Georgia Total Traffic Model for Charlotte, North Carolina Total Traffic Model for Chattanooga, Tennessee The Effect of City Population on Total Traffic Models Work Trip Models	

TABLE OF CONTENTS (Concluded)

Chapter | Page

Work Trip Model for Gainesville, Georgia
Work Trip Model for Chattanooga, Tennessee
Work Trip Model for Pittsburgh, Pennsylvania
Shopping Trip Models
Shopping Trip Models for Gainesville, Georgia
Shopping Trip Models for Chattanooga, Tennessee
Shopping Trip Model for Pittsburgh, Pennsylvania
Personal Business Trip Models
Personal Business Trip Model for Gainesville, Georgia
Personal Business Trip Model for Chattanooga, Tennessee
Personal Business Trip Model for Pittsburgh, Pennsylvania
Social and Recreation Trip Models
Summary of Results

VI. CONCLUSIONS 66

VII. RECOMMENDATIONS 69

Appendices

A. SAMPLE CALCULATIONS 72

B. FLOOR SPACE USE DATA 81

C. TOTAL TRIP MODELS 86

D. WORK TRIP MODELS 108

E. SHOPPING TRIP MODELS 113

F. PERSONAL BUSINESS TRIP MODELS 122

G. SOCIAL AND RECREATION TRIP MODELS 127

H. A BRIEF DESCRIPTION OF CURRENT TECHNIQUES FOR ESTIMATING FUTURE CBD FLOOR SPACE REQUIREMENTS 133

LIST OF REFERENCES 140

OTHER REFERENCES 142

VITA 144

LIST OF TABLES

Table		Page
1.	Trends in CBD Land Use	12
2.	Typical Floor Space Classifications Included in Groups Used by Harper and Edwards	36
3.	Models for Nine Cities Relating Total Person-Destinations to the CBD to Retail, Service-Office and Manufacturing Warehousing Floor Space Use	37
4.	Models for Nine Cities Relating Total Person-Destinations to the CBD to Retail and Service-Office Floor Space Use . .	40
5.	A Comparison of the Standard Errors and Correlation Coefficients of the Harper-Edwards Models with Models for Which the Manufacturing-Warehousing Coefficient Has Been Omitted .	41
6.	The Influence of the Number of Observations on the Regression Coefficients in a Three-Dimensional Linear Model	46
7.	Measures of Retail Activities for the Cities of Charlotte and Chattanooga	49
8.	Measures of Service-Office Activities for the Cities of Charlotte and Chattanooga	50
9.	A Summary of Results: Regression Models for the Cities of Gainesville, Charlotte, Chattanooga, and Pittsburgh	65
10-30	Total Trip Models - Appendix C	86
31-34	Work Trip Models - Appendix D	108
35-42	Shopping Trip Models - Appendix E	113
43-46	Personal Business Trip Models - Appendix F	122
47-51	Social and Recreation Trip Models - Appendix G	127

LIST OF FIGURES

Figure		Page
1.	Area of the CBD and Its Relation to Population of the Urbanized Area	6
2.	Number of Vehicles Entering the CBD in Relation to the Population of the Urbanized Area	6
3.	The Relationship of Vehicles Entering the CBD to the Area of the CBD	8
4.	The Relative Decline in Population of the Central City	9
5.	The Relative Decline of the Central City as a Center of Retail Trade and Manufacturing and Wholesale Employment	10
6.	Relationship of Work Trips to Employees	22
7.	Histogram for Retail Floor Space Use in Twelve Gainesville Origin-Destination Zones	28
8.	The Relationship of Retail Coefficients to City Population	43
9.	The Relationship of Service-Office Coefficients to City Population	44
10.	The Relationship of Zero Intercept Coefficients to City Population	45
11.	The Relationship of Shopping Trips to Gainesville CBD to Retail Floor Space Use	56
12.	The Relationship of Shopping Trips to Chattanooga CBD to Retail Floor Space Use	59
13.	The Relationship of Shopping Trips to Pittsburgh CBD to Retail Floor Space Use	61

GLOSSARY

Y_t Average 24-hour person destinations to CBD zone.

Y_i Average 24-hour person destinations from internal zones.

Y_w Average 24-hour person destinations to CBD zone for work.

Y_s Average 24-hour person destinations to CBD zone for shopping.

Y_b Average 24-hour person destinations to CBD zone for business.

Y_{cr} Average 24-hour person destinations to CBD zone for social and recreation purposes.

V_t Average 24-hour vehicle destinations to CBD zone.

V_w Average 24-hour vehicle destinations to CBD zone for work.

V_s Average 24-hour vehicle destinations to CBD zone for shopping.

V_b Average 24-hour vehicle destinations to CBD zone for business.

V_r Average 24-hour vehicle destinations to CBD zone for recreation.

V_c Average 24-hour vehicle destinations to CBD zone for social purposes.

X_s Area of floor space within zone used for retail sales.

X_r Area of floor space within zone used for services.

X_o Area of floor space within zone used for offices.

X_p Area of floor space within zone used for public purposes.

X_c Area of floor space within zone used for institutional purposes.

X_q Area of floor space within zone used for semi-public purposes.

X_a Area of floor space within zone used for amusement purposes.

X_h Area of floor space within zone used as hotels.

X_1 Area of floor space within zone used for retail sales.

X_2 Area of floor space within zone used for service-office purposes.

X_3 Area of floor space within zone used for manufacturing-warehousing purposes. X_1, X_2, and X_3 refer to the Harper-Edwards model.

SUMMARY

Traffic congestion and delays in the central city have persisted and in many cases grown worse despite efforts of traffic engineers to increase the capacity of city streets. A part of the difficulty lies in an inability to make reliable traffic forecasts as well as a lack of understanding of the fundamental nature of traffic flow. Additional study is needed therefore not only to provide supplemental forecasting techniques, but also to seek a basic understanding of human travel customs and practices. Additional research is most needful for the central business district, where travel activity is most intense and the problems most severe.

Suggestions have been made for several years that the traffic which moves in and out of a city each day is generated by the buildings in the central business district. A 1960 Queen's University (Kingston, Ontario) study by B. C. S. Harper and H. M. Edwards entitled A Study of the Generation of Person Trips by Areas in the Central Business District tended to confirm this thesis. The present research extends the results of the Harper-Edwards study by considering cities of a wide population range and developing relationships for trips made for various purposes.

In the present study, the results of origin-destination studies and central business district floor space surveys were used to develop linear and non-linear multiple regression equations which related person destinations to the central business district to various classifications of floor space use. More than 90 such models were developed by the

statistical least squares technique, and 42 of these models are shown in appendices to the report along with appropriate statistical data.

Subjects of the study were four cities ranging in population from 12,000 to 2,400,000: Gainesville, Georgia; Charlotte, North Carolina; Chattanooga, Tennessee; and Pittsburgh, Pennsylvania.

The study results show that the number of people attracted to zones in a city's central business district is closely related to the floor area within these zones being used for various purposes. The results suggest that for a given city it would be possible to develop satisfactory floor space models and that with these models and a reliable floor space forecast for the central business district, one could make suitable predictions of future traffic flow. It is further shown that suitable models may be constructed for the prediction of trips made for work, shopping, and business purposes as well as for total trips.

The results indicate that traffic flow to the central business district is most closely related to the following classifications of floor space use: retail sales, service, offices, and public floor space use. Traffic destinations were not statistically related to manufacturing, wholesaling, and semi-public floor space use.

Three dimensional linear regression models relating total destinations and retail and service-office floor space are shown for ten cities over a wide population range. It is demonstrated that the retail regression coefficients in these models increase slightly with increases in population, and that the service-office coefficients decrease with logarithmic increases in population.

CHAPTER I

INTRODUCTION

The past century has witnessed dramatic shifts in the growing population of the United States. In 1850, only 15 per cent of the population lived in urban areas. By the turn of the century, this percentage had risen to 40 per cent, and today, two out of three Americans live in urban areas. By the year 2000, it is estimated that the population of the United States will exceed 300 million. Well over three-fourths of the expected increase can be expected to occur in metropolitan areas.[1*]

Urban traffic congestion, always serious, has become increasingly severe as cities have grown and matured. Efforts by traffic engineers to deal with traffic congestion have largely been of a stop-gap nature, and more symptomatic than corrective. While the regulation of curb parking, provision of one-way streets, signalization of intersections, and the like have significantly decreased traffic delays and increased capacity, the problem of serious urban congestion remains.

Elimination of this problem is aggravated by the fact that urban transportation facilities are expensive and difficult to change. Once a transportation facility is provided, little can be done to change it radically for 20, 30, or more years.

---

*Superscript numbers refer to similarly numbered references in List of References at end of thesis.

Historically and to the present time, the central business district (CBD) has been the focal point for the city's population and has experienced the most serious traffic congestion and delays.

The need for reliable predictions of traffic flow to the central business district is becoming increasingly apparent. If predictions of future traffic flow to the central city are to be made with confidence, more must be learned of its basic nature and causes. The development of such basic data is a primary purpose of this study.

City planners and others have suggested for some time that traffic which is attracted to a city's central business district is closely related to the type and intensity of use of the buildings in that center. If this hypothesis is true, it implies that CBD traffic forecasts should be made by considering anticipated changes in CBD floor space use. Development of mathematical models relating CBD traffic to floor space use would not only provide an additional check on traffic predictions but would also provide for consistent and coordinated planning for traffic and land use in the CBD.

A 1960 study by Harper and Edwards[2] showed that the number of people attracted to CBD zones was closely related to floor space use within these zones. The authors of this study developed linear regression models for seven cities relating total person-destinations to three classifications of floor space use.

The intent of the present study was to extend the work of Harper and Edwards by developing multiple regression models for cities of a wide population range and for trips made for various purposes.

CHAPTER II

THE CHARACTER OF THE CENTRAL BUSINESS DISTRICT

The Census Bureau has defined the central business district as "an area of very high land valuation, an area characterized by a high concentration of retail businesses, offices, theaters, hotels, and 'service' businesses, and an area of high traffic flow."[3]

The CBD is an area of intense human activity. In retail trade, employment, recreation, and manufacturing activities, it dominates the central city of which it is a part as well as the surrounding suburbs.

Horwood and Boyce[4] conceive of the central business district as being comprised of a core which is surrounded by a frame. The CBD core is characterized by a high degree of land use and a heavy concentration of social and economic activity. Typical land uses in the core include: offices, retail sales, consumer services, banks, hotels, and theaters. The core is the hub of the city's mass transit system, and characteristically has the city's highest buildings. Growth of the core is usually vertical rather than horizontal, and its outer boundaries are determined by walking distances. The core constitutes roughly one-fourth of the area of the central business district.[5] It has only about 20 per cent of the parking spaces, but it is the destination of more than two-thirds of the CBD shoppers.[6]

In contrast to the core, the CBD frame has little retail land use. Characteristic land uses in the frame are: automotive sales and services;

off-street parking; medical and dental services; wholesaling; light manufacturing; transportation terminal facilities; and multifamily residences.

Some[3] contend that areas with land uses which are predominantly wholesaling, light manufacturing, and multifamily residences should be excluded from any demarcation of the CBD. Another difficulty of the core-frame concept is that its proponents have provided no standard method for locating the boundaries of these areas.

Delimitation of the CBD

A method for delimiting the central business district has been proposed by Murphy and Vance.[7] This method is briefly described in the following paragraphs.

> It involves, first of all, land use mapping of an area around the PLVI (Peak Land Value Intersection) extensive enough to include everything that by any stretch of the imagination might be considered as belonging in the District. From the field sheets three maps are made for each city: one of ground floor use, one of second floor use, and a third map on which the uses of the third and higher floors are generalized in such a way that the total floor areas in various uses on the third and all higher floors can be arrived at. Calculations from these three maps form the basis for the CBD delimitation.
>
> A fundamental element of the method is the designation of certain types of land use occupance as non-central business in character. These include residential, governmental and organizational, industrial, wholesaling and commercial storage, and vacancy. In contrast, all other land uses are considered to be central business uses.
>
> The technique involves, also, the application of two indexes. To be considered as lying within the CBD a block has to have a Central Business Height Index (CBHI) of one or more; that is, central business uses (in contrast to non-central business uses) have to average one story or more for the block. Secondly, the block has to have a Central Business Intensity Index (CBII) of 50 per cent or more; that is, at least

> 50 per cent of all floor space at all levels combined has to be in central business uses. In addition to qualifying on the bases of both of these indexes, the block has to be one of a contiguous group of such blocks surrounding the PLVI.

The Murphy-Vance technique provides a scientific approach to the problem of standardizing the delimitation of the central business district. However, it has not been generally used in the development of origin-destination traffic surveys.

The Size of the CBD and Its Influence on Traffic Flow

The central business district occupies a relatively small part of the urbanized area, its proportionate area being less than 0.5 per cent for the large cities and only about 4 per cent for the smallest cities. The area of the CBD increases with increase in city population, but at a decreasing rate.

A Bureau of Public Roads study[5] of 69 cities reports that cities in the 10,000-25,000 population range had nine times as much CBD area per capita as cities of over one million. The relationship of CBD area to city population is shown by Figure 1.

The central business district is "the major destination of traffic movements in an urbanized area."[5] However, its relative importance as an attractor of traffic decreases with increase in city size.[8] Fourteen times as many vehicles per capita may enter the CBD in cities of 5,000-10,000 population as in the cities with more than 1 million population.[5] Primary reasons for this phenomenon are: scarcity of parking spaces, availability of mass transit facilities, and opportunities for more diverse trip patterns in larger cities. The relationship of the number of vehicles entering the central business district to the metropolitan area population is illustrated by Figure 2.

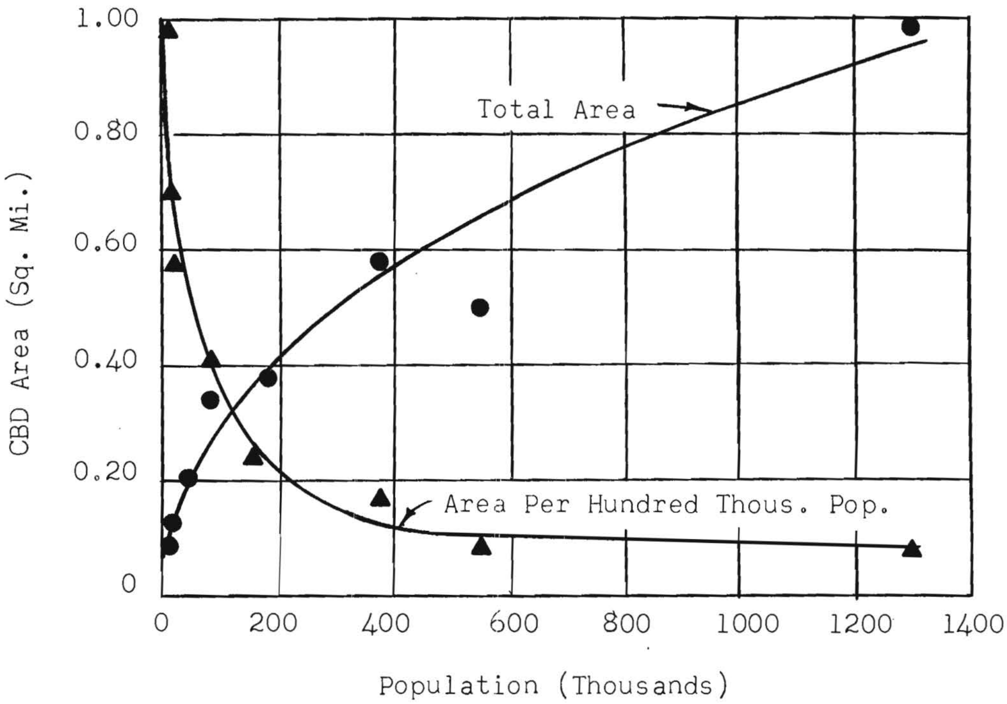

Figure 1. Area of the CBD and its Relation to Population of the Urbanized Area.

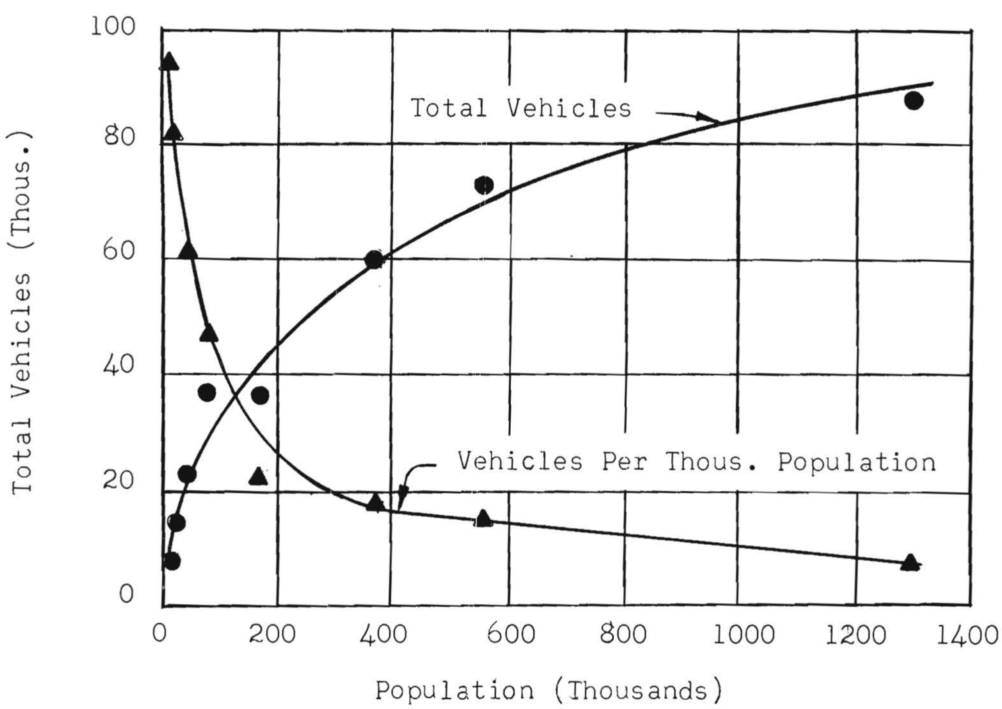

Figure 2. Number of Vehicles Entering the CBD in Relation to Population of the Urbanized Area.

Comparing the curves of Figures 1 and 2, a remarkable similarity is noted. This similarity leads to the hypothesis that traffic flow to the central business district is closely related to CBD area. A plot of CBD area and vehicle flow to the CBD appears to corroborate this hypothesis (Figure 3). For cities with populations less than one million, the number of vehicles entering the CBD is linearly related to CBD area. This relationship does not appear to be valid for more populous cities, and the data suggest that increases in central business district area beyond about 0.6 square mile do not attract a proportionate number of vehicles to the CBD.

The CBD in Transition

In most cities, the central business district has experienced remarkable shifts in land use in recent years. While these changes have been occurring for 50 or more years, the most rapid change has occurred since the end of World War II.

Population growth, higher family incomes, and increased ownership and popularity of the automobile have contributed to a relative decline in the population of the central city as shown in Figure 4. Suburban residential growth has been followed by decentralization of sales, industrial, and professional activities. The relative decline of the central city as a center of retail trade and manufacturing and wholesale employment is illustrated by Figure 5.

Perhaps the extent of decentralization of American cities is most clearly seen by a consideration of trends in retail sales. In a study of 55 metropolitan areas, McMillan[9] reported that suburban retail sales increased 53 per cent from 1948 to 1954, while sales in the CBD increased

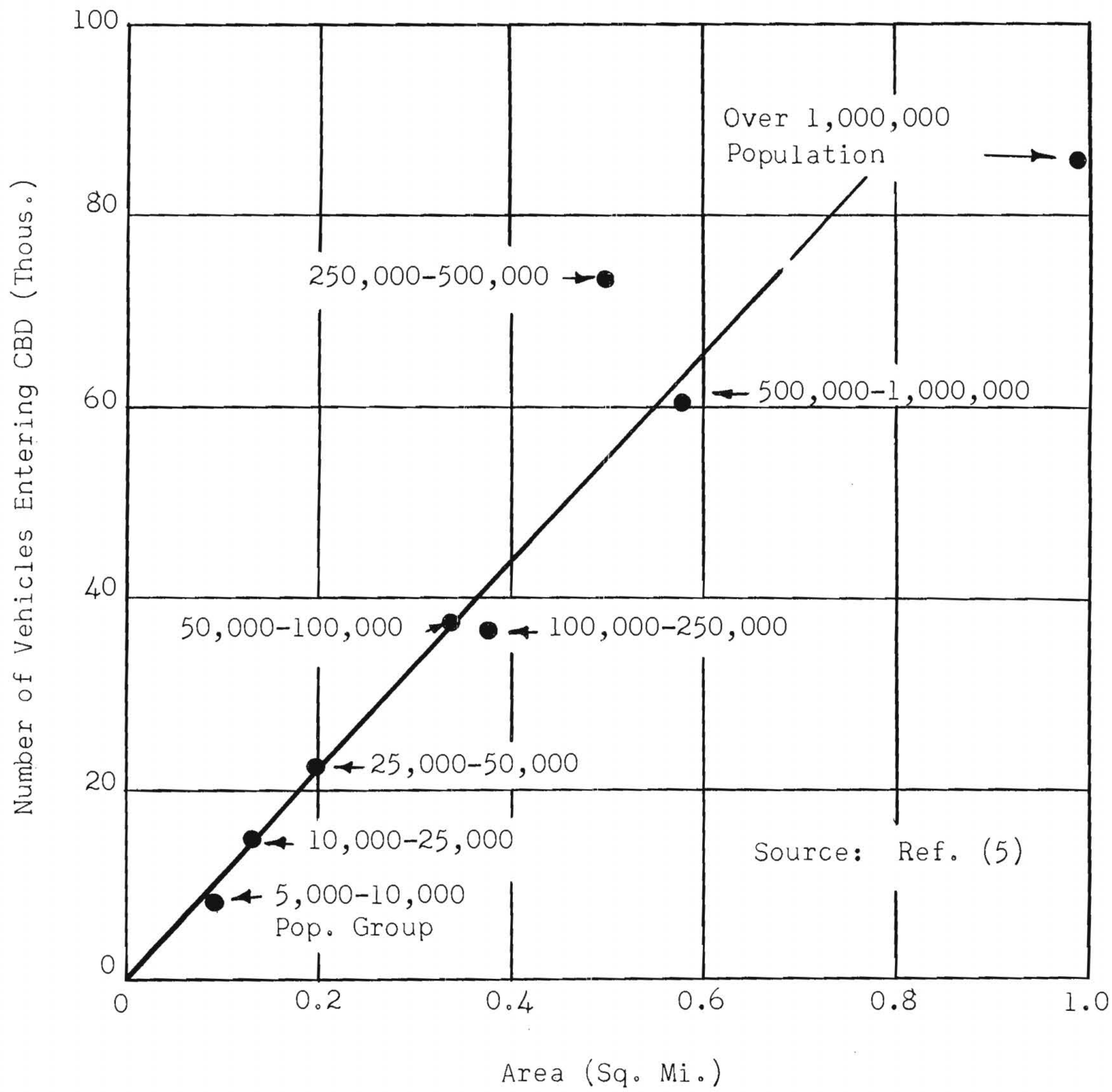

Figure 3. The Relationship of Vehicles Entering the CBD to the Area of the CBD.

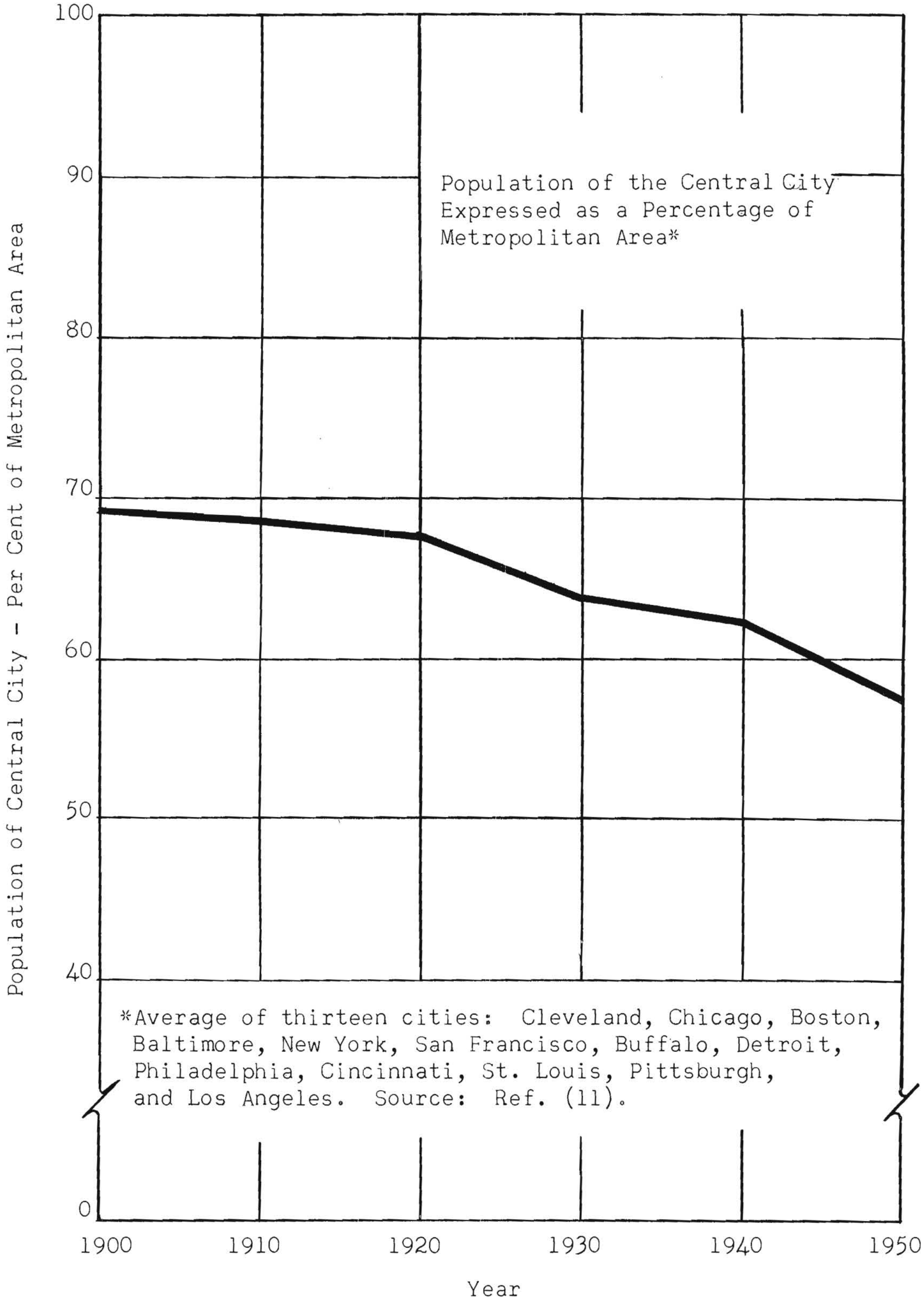

Figure 4. The Relative Decline in Population of the Central City.

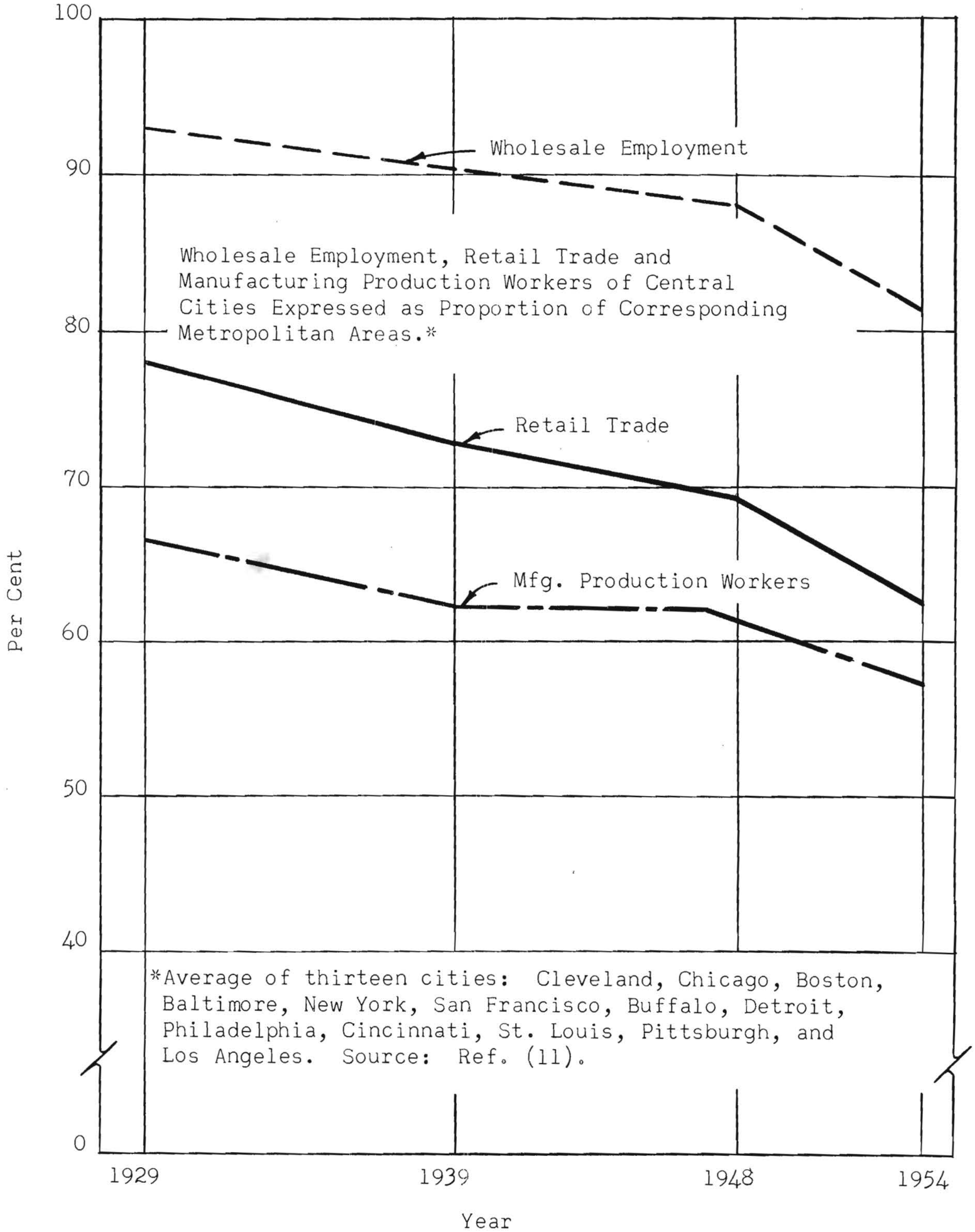

Figure 5. The Relative Decline of the Central City as a Center of Retail Trade and Manufacturing and Wholesale Employment.

only one per cent. During this same period, the proportion of retail sales in CBD's decreased from 18.8 per cent to 15.9 per cent of total sales.

Changes in retail sales activities have been accompanied by similar decreases in wholesale and industrial activities in the CBD. However, in most cities, the importance of the CBD an an employment center has remained stable or increased.

The rapidly changing nature of the central business district is mirrored in a Clark University land use study[3] of Long Beach and Oakland, California, and Richmond, Virginia. In this study 67 per cent and 32 per cent gains in Service-Financial-Office land use were reported for Oakland and Long Beach, respectively, during a seven year period. During this same period, retail land use in Oakland gained only 3 per cent, while Long Beach reported a 7 per cent decline in retail land use. During a four-year period, the Richmond CBD experienced a 4 per cent increase in Service-Financial-Office use, while all other land uses declined. A breakdown of the findings of this study are given in Table 1.

At first glance, one might expect these functional and land use changes to lessen the traffic difficulties of the CBD. However, while the central business district has declined in relative importance as a traffic attractor, absolute volumes of traffic flow to the CBD have in most cases increased.

Even in terms of retail sales, where sharpest relative declines have been noted, for most cities the decline in absolute terms was small or non-existent. Retail sales in the Washington, D. C. CBD, for example, declined only 0.4 per cent from 1954 to 1958 even though its proportionate

Table 1. Trends in CBD Land Use*

City	Percentage Change Richmond	Long Beach	Oakland
Time Interval	1956-1960	1953-1960	1953-1960
Land Use			
Retail Business	- 6.3	- 6.7	+ 3.0
Service-Financial-Office	+ 4.3	+ 32.4	+ 66.9
Public and Organizational	- 11.4	- 10.7	+ 40.8
Industrial	- 15.9	+ 40.0	- 38.2
Wholesale and Storage	- 44.5	- 31.6	- 5.3
Residential	- 9.0	+ 17.6	+ 36.6
Vacant Lots and Buildings	+ 23.3	+ 35.6	+ 51.6

Source: Reference (3)

*NOTE: In this study, which utilized the Murphy-Vance delimitation technique, service-financial-office land uses accounted for 50 per cent of the total land use; retail business, 27 per cent; and public and organizational, 8 per cent. Since the Murphy-Vance technique classifies industrial, wholesale, and residential uses as non-central uses, the percentages of total land use for these categories are understandably low.

share declined from 20.2 per cent to 16.1 per cent of the total.[9] During this same period, retail sales in Atlanta's CBD, while experiencing a relative decline, increased in absolute terms 13.2 per cent.[9]

While retail, manufacturing, and wholesale employment have become decentralized, office employment in the CBD has increased. In most cities, the central business district remains a major employment center, attracting large numbers of work trips during periods of peak traffic flow.

Peak hour traffic congestion has been aggravated by a decreasing utilization of mass transit facilities in favor of private automobiles. This trend is well illustrated by cordon count data for Los Angeles. Thirty-five per cent of all people entering downtown Los Angeles in 1924 came by car; in 1940, 56 per cent; and in 1960, 75 per cent.[10] Similar declines in mass transit utilization have been experienced in most cities of the United States during this same period.

Thus, because of population growth, construction of offices and government buildings in the central area, and changes in travel mode, traffic congestion in the CBD has not improved. It is ironical that as the central business district has declined in relative importance as an attractor of traffic, congestion there has not abated, and in many cases has grown worse.

The Future of the CBD

The past trends in the shifting character of the central business district are likely to continue into the future, but at a slower rate. While slight declines in relative importance are likely, there is little question but that the CBD will continue to be the dominant center of financial, cultural, and government activities. "There is," in the words of Vernon,[11] "every reason to expect continued vitality."

The most significant changes to the CBD that are likely to be experienced in future years are: (1) further relative declines as a retail sales center; (2) more decentralization of manufacturing and wholesale establishments; (3) absolute increases in office and government employment; and (4) increased use of the CBD for social, cultural, and residential purposes.

In a recent paper,[12] Wilbur Smith summarized current informed opinion regarding probable future changes in the CBD:

> The CBD will not generally increase in dominance in the future and will be subject to growing competition from outlying commercial areas. Its stabilization and decline in <u>relative</u> importance will result from continual urban population dispersion, the consequent proximity of competitive outlying areas, and the shift of non-essential activities to new, low-cost sites.
>
> The CBD will, however, continue to be the vital and dominant focal point of the area, and will increase as a cultural and social center. In many cities, downtown office functions, including governmental offices, can be expected to increase.
>
> Functionally, the CBD will continue to become more specialized, not merely in the activities taking place but also in their location in clusters within the area. Further decentralization of retail, manufacturing, and wholesaling employment is likely.
>
> In keeping with the changing functions of the CBD will be the development of high-rise or luxury apartments within or near the core area. These, as well as the emergence of new multi-storied office buildings, will broaden the tax base and tend to offset losses that have resulted from dilapidated or outmoded properties.

Few traffic engineers and city planners believe that the CBD traffic problem will improve with a mere passage of time. Indeed, more serious traffic congestion in the city center is likely unless positive steps are taken to provide improved terminal and circulation facilities.

CHAPTER III

THE PREDICTION OF THE TRAFFIC FLOW TO THE CBD

Bitter experience has shown that urban transportation facilities must not be based on routine extrapolation of past traffic trends. Public interest demands that traffic and terminal facilities be based on informed engineering judgement and reliable traffic predictions. If obsolescence and economic waste are to be avoided, it is apparent that up-to-date scientific prediction techniques must be used.

A great deal of progress has been made in the field of urban traffic prediction during the past ten years. During this period, the most notable trend has been the increasing reliance on mathematical models and formulae. A complete enumeration and description of these techniques is beyond the scope of this thesis. Furthermore, a full account of the methodology that has been applied would be inappropriate here, as adequate descriptions are available in the literature. It does seem important, however, to make brief comments on current approaches to the problem, and to point out certain inadequacies in order that the current study may be seen in proper perspective.

In most of the metropolitan transportation planning studies which have been conducted in the past decade, future travel projections have been based on relationships which have been found to exist between the existing patterns of traffic flow and "land use." Analysis of origin-destination studies has shown that generation of trips in residential areas is influenced by such factors as family income, automobile ownership, residential density, and distance from the city center. In non-residential zones, employment, retail sales, area of building or land in use, and other such factors have been taken as indices of "land use" generation. Typically, estimates of future trip volumes between any two zones have been based on anticipated changes in land use within the two zones.

Because most traffic projections are based on the results of a single origin-destination study, it has usually been necessary to assume that traffic generation rates remain constant with time. There is reason to suspect that this assumption is not correct. Recent studies of Washington, D. C., for example, showed a significant reduction of night time travel for recreational and social purposes and a corresponding increase in travel for the purpose of shopping.[13]

Commenting on the dangers involved in assuming constant trip generation rates, Kennison[14] observed:

> The present knowledge of these rates has been based largely on empirical observations with little information becoming available concerning the basic motivations of trip making. The fundamental reasons for trip making, the criteria for the selection of destinations, and the values placed by individuals on terminal conditions, routes, modes of travel, time of day, and trip expense remain unquantified.

The Fratar Method

In many recent highway planning studies, future trip estimates between any two zones were made by expanding present trip interchanges in accordance with expected land use changes within the two zones. Fratar[15] proposed an iterative technique in 1954 which would provide consistent estimates by harmonizing the mutual effects of interchanges among all the pairs of zones in the study area. However, according to the Fratar method, if the traffic volume between two zones is zero in the survey data, then the traffic estimate for the design year is also zero.[16] This is a serious limitation as a large proportion of future traffic is expected to be generated by areas yet undeveloped.

Gravity Models

Many traffic engineers feel that a more realistic approach to estimating future trip interchanges is provided by the gravity model.[17] The gravity model provides a means by which patterns of trip interchanges are synthesized according to the relative availability of opportunities for interchange of trips between the various zones. Beginning with an estimate of future trips generated by a particular zone, the gravity model formula distributes these trips in proportion to the relative attraction of an area and inversely proportioned to some power function of the distance (or travel time) between the areas.

Despite its popularity, the gravity model is seriously limited by its extreme sensitivity to time-distance relationships.[18] Estimations of the total number of trips generated by a residential zone can be made with a relatively high degree of precision. Furthermore, even if errors in total traffic growth are made, it may be possible to lessen the consequences of these errors by modifying the timing of the construction of new transportation facilities. However, the magnitude of travel time-distance errors may be much greater, and the consequences much more serious. In the Chicago Area Transportation Study, for example, it was assumed that average automobile trip length will remain constant during the next twenty years. If, instead, it had been assumed that the average travel time will remain constant, a different alternative would have been indicated as the optimum transportation plan.[19]

Wilbur Smith has noted that "estimates of travel between districts are subject to considerably more variability than estimates of total trip production because so much depends on the quality and capacity of highways which link districts together."[18]

Floor Space Models

Recognizing "the limitations of existing methods of forecasting future travel within cities," the Ontario Department of Highways sponsored research at Queen's University in 1958 "in an attempt to develop new forecasting techniques."[2] In this study, multiple regression was used to relate traffic flow to the CBD to the following classifications of floor space use within the CBD: (1) Retail; (2) Service-Office; and (3) Manufacturing-Warehousing.

The central business district was chosen for study by Harper and Edwards because "there seemed to be a serious gap in the development of the methods for evaluating travel to the city centre."

The study report, which was published in 1960, concluded that there is a close relationship between the number of people attracted to an area in the CBD to the amount of floor space used for various purposes within that section of the CBD.

Since the Harper-Edwards study was principally concerned with cities with populations over 600,000, city population seemed to have little effect on the models that were developed.

Harper and Edwards made no attempt to develop models for trips made for a particular purpose, nor was any attempt made to develop models using various combinations of floor space use. Their important study was limited to the development of only eight models for the prediction of total person-destinations.

CHAPTER IV

METHOD OF STUDY

Using the Harper-Edwards study as a starting point, efforts were made in this research to develop floor space models for cities over a wide population range and for trips made for various purposes. CBD floor space inventories and origin-destination traffic studies were obtained for the cities of Pittsburgh, Pennsylvania; Chattanooga, Tennessee; Charlotte, North Carolina; and Gainesville, Georgia. Choice of these particular cities was dictated primarily by the availability of suitable traffic and floor space data. For each of these cities, floor space data was assembled and tabulated by origin-destination (O-D) zones. Multiple regression models were developed relating traffic flow to CBD zones to floor space use within these zones. Various classifications of floor space use were related to total trips and also to trips made for the following purposes: Shopping, Work, Personal Business, Social, and Recreation. In these models, traffic was regarded as the dependent variable and various classes of floor space use as independent variables. In effect, this assumes that changes in average traffic volumes attracted to a CBD zone are caused or explained by changes in the magnitude of one or more classifications of floor space use.

For the Pittsburgh, Charlotte, and Gainesville studies, trips were expressed in 24-hour person-destinations. Due to the manner in which traffic was reported in the origin destination study, trips were generally expressed as 24-hour vehicle destinations in the Chattanooga models. Floor space use was expressed in thousands of square feet.

In an effort to evaluate the influence of city size, predictive models were developed relating total 24-hour person destinations to three categories of floor space use: Retail, Service-Office; and Manufacturing-Warehousing. These same floor-space groupings were used by Harper and Edwards[2] to develop models for seven cities ranging in size from 275,000 to 3,670,000 population. These particular models were therefore comparable with those developed by Harper and Edwards, and from this comparison, it was possible to obtain some measure of the influence of city size.

Linear Regression

With but few exceptions, all models were developed using simple and multiple linear regression techniques. Basically, linear regression involves determining the parameters or coefficients in a linear equation which best describes or fits a set of observations. In simple linear regression, the problem is to determine the coefficients b and K in an equation of the form

$$y = bx + K \quad .$$

For example, simple linear regression was used to relate work trips to CBD zones in Chattanooga to the number of employees in each zone, producing the following equation:

$$\text{Work Destinations} = 0.826 \text{ (No. of Employees in Zone)} - 26 \quad .$$

A dot chart and regression line for this relationship is shown as Figure 6.

Similarly, in multiple linear regression, it is necessary to determine the coefficients b_1, b_2, b_3, K in an equation of the form:

$$y = b_1x_1 + b_2x_2 + b_3x_3 + \ldots + K \quad .$$

In this case, it is assumed that the dependent variable is influenced not by one but by two or more independent variables. While the method for determining the multiple regression coefficients are similar to those used for simple regression, the multiple regression surface exists in three or more dimensions and cannot be easily plotted or sketched.

Essentially the problem of regression is to determine the line or surface which "best-fits" the observed points. While there are a number of methods for determining the line or surface of "best-fit," the technique used in this study was the well-known method of least squares.

The method of least squares may be defined as follows: If, for the dependent variable y, the difference between the observed values and the predicted values is determined, squared, and summed; then this sum will be a minimum for the least squares line or surface. That is to say, the least squares line or surface is the "best-fit" in the sense that the sum of the squares of the errors is as small as possible.

In this study, the least square calculations were made with the aid of an electronic computer. The calculations may, of course, be made by hand or with the use of a desk calculator. To illustrate the steps involved in the least squares technique, sample calculations are presented as Appendix A to this report.

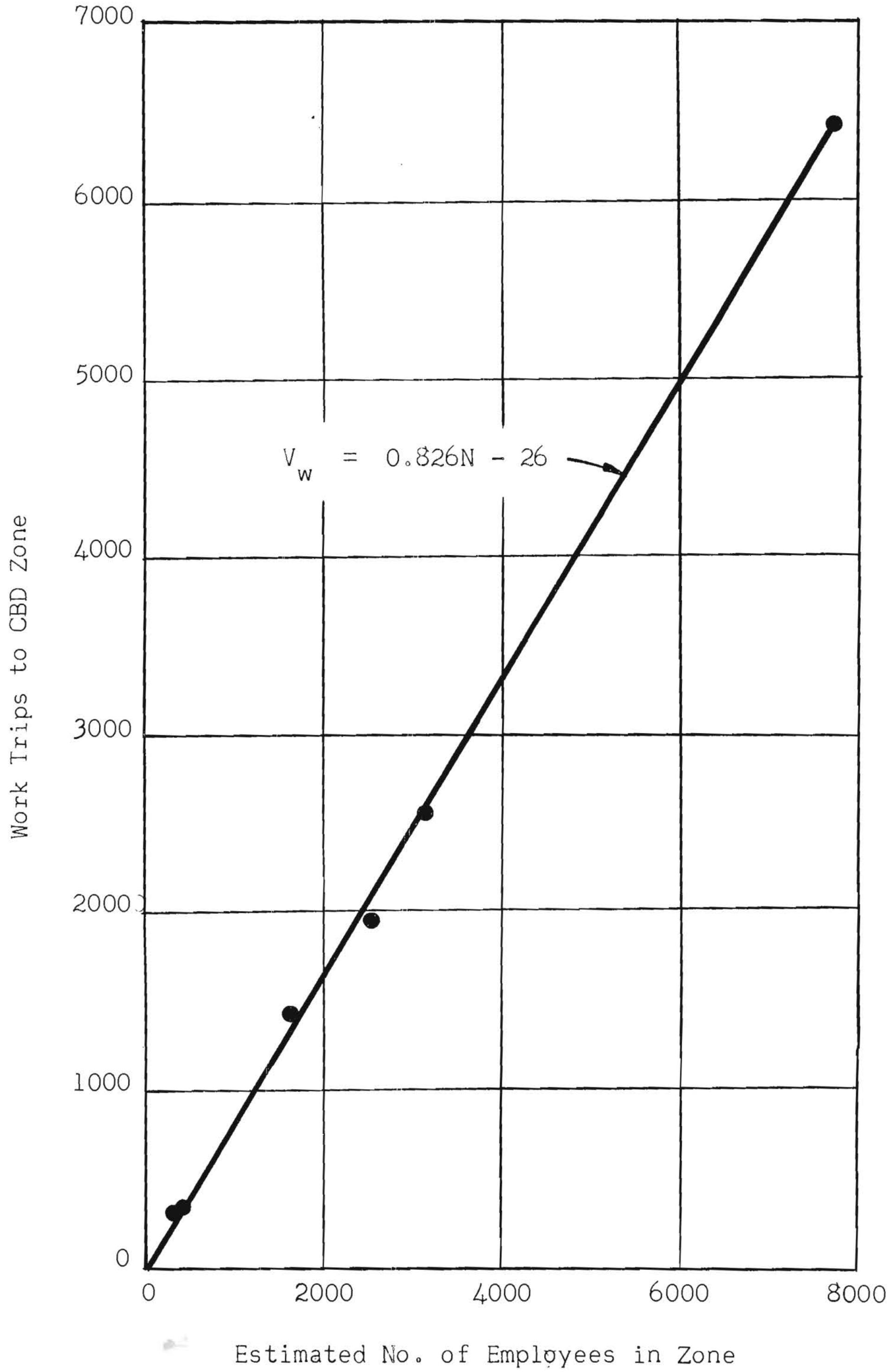

Figure 6. Relationship of Work Trips to Employees.

Statistical Measures of Correlation and Regression

In the paragraphs which follow, certain measures of importance are discussed, both for the regression model as a whole and for the individual variables.

Measures of Importance of the Regression Model

Having developed a predictive regression model, it is helpful to obtain some measure of its effectiveness. Several statistics may be computed which serve to evaluate the model and to measure its worth. The meanings of four such statistics, which were used in this study, are briefly stated below. For more detailed information on these statistical measures, reference may be made to a number of available textbooks.[20,21]

Standard Error of Estimate. The standard error of estimate measures the closeness with which the estimated values agree with the observed values. A "small" standard error indicates close agreement between traffic values computed by the model and traffic actually observed. The standard error is expressed in the same unit as the dependent variable, which for most of the models developed in this study were person-trips or vehicle-trips.

Coefficient of Multiple Determination. The coefficient of multiple determination measures the proportion of variation in the dependent variable which is explained by, or associated with, differences in the independent variable or variables. Large values of the coefficient of multiple determination, which range from 0 to 1, are indicative of a close degree of association between the dependent and independent variables. In this study, for example, a coefficient of multiple determination of 1 would indicate that all of the variation in traffic flow to the CBD could be explained by variations in floor space use, while a value of zero would indicate that traffic and land use are not related.

Coefficient of Multiple Correlation. The square root of the coefficient of multiple determination is called the coefficient of multiple correlation, or more simply, correlation coefficient. It also serves as a measure of the degree of association between the dependent and independent variables. However, it tends to overestimate the association between the dependent and independent variables, and in this sense is inferior to the coefficient of multiple determination as a measure of this association.

The F Ratio. The F Ratio is the ratio of the variation explained by the model to the residual or unexplained variation. Roughly speaking, it may be stated that "large" values of the F Ratio are indicative of "good" predicative models. An F Ratio of zero would indicate no correlation between the dependent and independent variables, while perfect correlation between the variables would require an F Ratio of infinity.

Measures of Importance of Individual Variables

In addition to attempting to measure the effectiveness of the total mathematical model, measures were made of the regression and correlation of the individual variables. The importance of each variable was shown by a study of its regression coefficient, standard error, partial correlation coefficient, and level of significance. The meaning of each of these measures is briefly stated in the paragraphs that follow.

The Regression Coefficient. A simple regression coefficient shows how many units the dependent variable changes for each unit change in the independent variable. In simple regression, the regression coefficient measures the slope of the regression line. Similarly, in multiple regression, a net regression coefficient shows the relation of the dependent variable to the concomitant independent variable, excluding the influence of the other independent variable or variables. The net regression coefficient of an independent variable measures the slope of the regression line when all other independent variables are taken to be zero.

In this study, the regression coefficients serve as a measure of the attractive strength of the corresponding floor space use. However, a regression coefficient of 4.0 for retail floor space use does not imply that each unit of retail floor space attracts four units of traffic. Caution must therefore be exercised in evaluating the regression coefficients, recognizing the nature of the model of which the coefficient is a part. For example, in a Chattanooga model for total trips, the coefficient of service floor space use when considered in conjunction with retail floor space use alone was 12.69. However, the coefficient of service floor space use when considered in conjunction with retail and institution floor space use was only 10.24. This apparent discrepancy is explained by the fact that the two coefficients do not measure the same thing. The value of 12.69 shows the average increase in traffic for each unit increase of service floor space use, but without making any allowances for differences in institution floor use. The coefficient of 10.24 shows the average increase in traffic, with both retail and institution floor space use remaining unchanged. The two models alluded to above may be seen in Tables 15 and 16.

The Standard Error of the Regression Coefficient. The standard error of the regression coefficient furnishes a measure of the accuracy of the estimated regression coefficient. Expressed in the same units as the regression coefficient, the standard error measures the closeness with which the estimated coefficient agrees with the "true" regression coefficient. Assuming that the observations are normally distributed about the regression plane, a confidence interval may be computed using the "t"-distribution at the desired level of risk.

Partial Correlation Coefficient. A partial correlation coefficient measures the correlation between the dependent variable and each of the independent variables. For a given independent variable, the partial correlation coefficient measures only the effect of that variable; any linear tendency of the remaining independent variables to obscure the effect is eliminated. Squared, the partial correlation coefficient shows how much that variable reduces the variation after all of the other variables are taken into account.

Level of Significance. Each regression coefficient was tested at the 0.1, 1, and 5 per cent levels of significance using the Student's "t" test. To say that a regression coefficient is significant at the 0.1 per cent level of significance means that this result would be expected purely by chance only once in 1000 times; a coefficient significant at the 1 per cent level means that that value would arise one time in 100 by chance, and so on.

It should be noted that the calculation of meaningful correlation statistics requires that strictly random samples be taken from normal bivariate or multivariate universes. This means: (1) that the joint frequency distributions of the variables in the sample must be representative of the corresponding distribution in the universe; (2) that the distribution of each variable must tend to follow the normal frequency curve; and (3) that the standard deviations of the dependent variable must remain constant within normal sampling fluctuations.[20]

Because the number of available observations was relatively small, conclusive checks could not be made to determine if all of the above requirements were fulfilled. However, there are reasons to believe that certain of these requirements were not met. For example, the frequency distributions of the variables appear not to follow the normal frequency curve but rather seem to be positively skewed. This is illustrated by a histogram for certain of the floor space values for Gainesville, shown as Figure 7. Furthermore the grouping of CBD blocks into Origin-Destination zones is not done randomly, but contiguous blocks are grouped into zones more or less arbitrarily depending upon the judgement of the individual who performs this grouping.

Fortunately, estimates of the regression coefficients are not as seriously affected by departures from the required conditions as are estimates of correlation coefficients. The most serious results of these departures is to cause the computed correlation statistics (correlation coefficient, partial correlation coefficient, standard error, etc.) to be misleading.

While it is risky to base strict probability statements upon the correlation statistics, it is believed that these values do serve as an approximate measure of the effectiveness of the variables and the models, and are especially helpful in comparing two or more models which describe the same traffic flow in the same city.

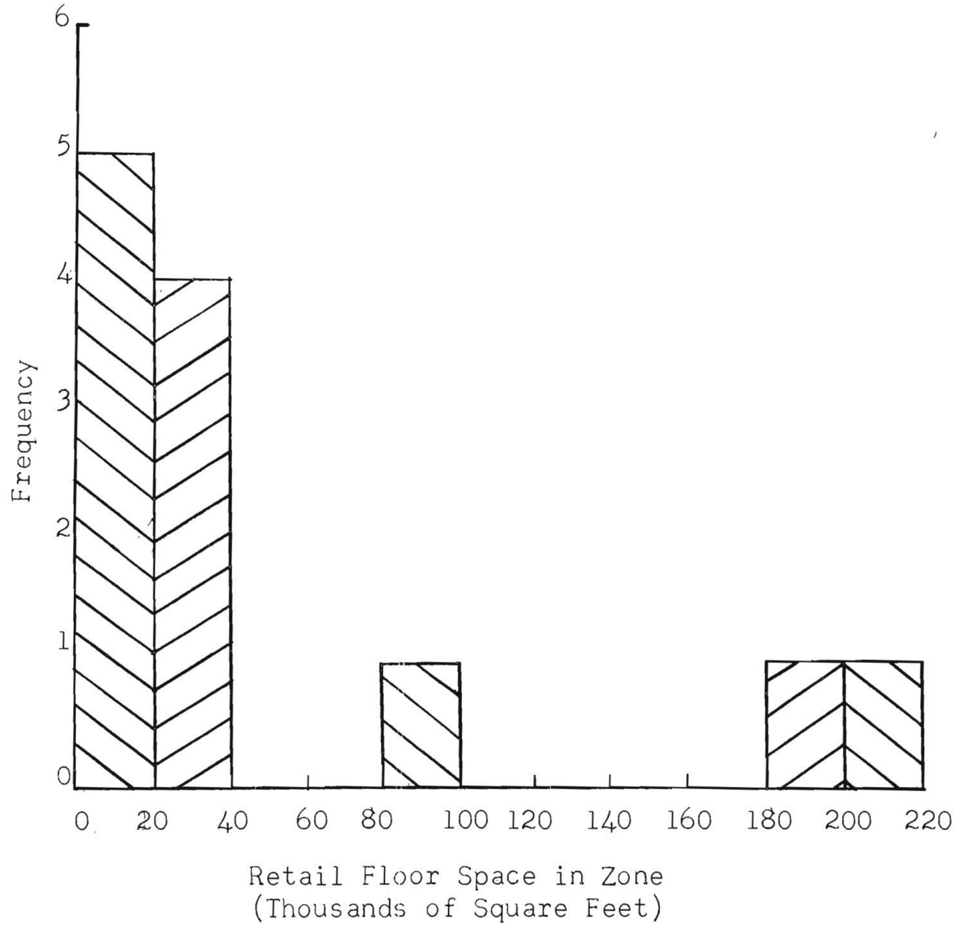

Figure 7. Histogram for Retail Floor Space Use in Twelve Gainesville Origin-Destination Zones.

CHAPTER V

RESULTS

In this study, more than 90 regression equations were developed relating traffic flow to the central business district to floor space use within the CBD. Models were developed for total traffic destinations as well as for trips made for work, shopping, business, social, and recreation purposes. The most satisfactory models are described in succeeding paragraphs and in tables which are included as appendices to this report.

The study encompassed an analysis of traffic-floor space relationships for four cities of the eastern United States:

1) Gainesville, Georgia, a center of trade and local government in rural north Georgia with a population of 17,000;

2) Charlotte, North Carolina, a city of wholesale trade, finance, insurance, and real estate with a population of 202,000;

3) Chattanooga, a diversified city of 283,000 in southeastern Tennessee; and

4) Pittsburgh, Pennsylvania, a city of 2.4 million people.

Some difficulty was experienced in the computer tabulation of the Charlotte traffic data by trip purpose. The values used for Charlotte trips made for work, shopping, business, and social-recreation can therefore only be taken as approximate. As a result, little confidence can be placed in the models developed from these data. While these models are included in the appendices in the interest of completeness, their value is questionable.

In the following equations, the symbol Y refers to average 24-hour person destinations to the central business district, while the symbol V refers to vehicle destinations. The letter X is used to denote floor space in use in thousands of square feet. X_s refers to floor space used for retail sales purposes; X_o denotes office use; and X_p, public use. The symbol X_r refers to floor space devoted to personal and business services; and X_c denotes floor space classified as "institutional."

Total Traffic Models

In developing total traffic models for Gainesville, Charlotte, and Chattanooga, it was found that total trips to the CBD are most closely related to sales, service, office, and public floor space use.

Total Traffic Models for Gainesville, Georgia

Equation (1) is the best total trip model developed from Gainesville data:

$$Y_t = 8.98X_s + 21.12X_o + 63.26X_p + 216 \quad . \qquad (1)$$

With an F Ratio of 90.82, this model is highly significant. The coefficient of multiple determination of 0.956 suggests that over 95 per cent of the variation in traffic during this period was explained by the equation. Reasonably close agreement between the observed traffic values and those computed by equation (1) was noted. This is shown by a small standard error and by a zone-by-zone comparison of computed and observed trips shown in Table 10, Appendix C.

The partial correlation coefficients indicate that total person-trips attracted to Gainesville's CBD are closely related to retail sales, office, and public floor space use. Partial correlation coefficients for sales, office, and public floor space were respectively 0.827,0.907, and 0.822. The regression coefficient for office floor space (b_o) was most significant, being significant at the 0.1 per cent level. The regression coefficients for public (b_p) and sales (b_s) floor space were both significant at the one per cent level. Total traffic to the Gainesville CBD showed little correlation with service, wholesale, manufacturing and, semi-public floor space use.

It is interesting to note that the regression coefficient for public floor space use is more than seven times that of sales floor space and almost triple that of office floor space. This suggests that Gainesville's public floor space exerts a much stronger relative attraction to traffic than do retail sales and office floor space. In this is reflected the important civic and governmental functions served by Gainesville as the county seat of Hall County. These coefficients may also show that sales space is not intensively used in Gainesville and that overcrowding may prevail in public spaces.

A similar model was developed by relating sales, office, and public floor space use to traffic attracted from the internal area (i.e., the urbanized area defined by the origin-destination cordon line).

$$Y_i = 4.74X_s + 14.48X_o + 29.07X_p + 94 \quad . \qquad (2)$$

Correlation statistics for this equation also imply that traffic destinations and CBD floor space use are strongly related. Equation (2) was characterized by a large F Ratio and correlation coefficient and a small standard error. These values are given in Table 11, Appendix C, along with a comparison of traffic destinations computed by the predictive model and those observed in the origin-destination survey. It is noted that the computed and observed traffic values are remarkably similar for the four central zones where traffic is highest.

A comparison of equations (1) and (2) suggests that about one-third of the trips attracted to office space and about one-half of the trips to public and sales floor space originate from areas beyond the internal origin-destination cordon. This reflects the county-wide influence exerted by the rural county seat. In contrast to more populous cities, a large percentage of trips to the Gainesville CBD originate in the rural hinterland where there are no shopping and work centers to compete with those in the central city.

Total Traffic Model for Charlotte, North Carolina

A very satisfactory model was developed relating total person destinations to the Charlotte CBD to floor space used for sales, services, and offices.

$$Y_t = 10.62X_s + 9.29X_r + 15.01X_o + 2343 \quad . \qquad (3)$$

Equation (3) was significant at the 2.5 per cent level. The model was characterized by a high correlation coefficient and a small standard error of estimate. The agreement between observed traffic values and those computed by the model was remarkably close. In no case did the computed destinations vary more than four per cent from the observed destinations.

With only five observations (O-D Zones), none of the regression coefficients were significant at the ten per cent level. The sales and office regression coefficients were significant at the 20 per cent level and the service coefficient at the 30 per cent level. Partial correlation coefficients for all variables exceeded 0.90.

The regression coefficients for equation (3) suggest that sales and service floor space use in Charlotte attracts about ten daily person-destinations per 1,000 square feet, and office floor space use about fifteen.

Total Traffic Models for Chattanooga, Tennessee

Although there were only six origin-destination zones in the Chattanooga CBD, the least squares models for the most part were very satisfactory. The most satisfactory total trip model related total person-destinations to three categories of floor space use: retail sales; personal and business services; and institutions.

$$Y_t = 7.30X_s + 13.56X_r + 7.02X_c - 25 \quad . \tag{4}$$

Very close agreement between the observed trips and those computed by equation (4) are shown in Table 13. Closest agreement is noted for zones 511 and 515 where traffic activity is most intense.

Total traffic flow to the Chattanooga CBD was most closely related to retail sales and personal and business service floor space use. For equation (4), partial correlation coefficients for sales and service floor space use, respectively, were 0.945 and 0.962. Although institutional floor space use was found to be a significant variable, very satisfactory results were obtained when person-trips were related to sales and service floor space alone, resulting in equation (5).

$$Y_t = 5.17X_s + 16.72X_r + 512 \quad . \tag{5}$$

This model, being three dimensional rather than four, is simpler to apply than equation (4). Its standard error was 1181 as compared to a standard error of 872 for equation (4). (See Table 14.) The correlation coefficient for both models was larger than 0.99. Equations (4) and (5) were both significant at the 0.5 per cent level.

Worthy of special mention in equations (4) and (5) are the relatively large regression coefficients for the personal and business service floor space variable. These coefficients indicate that service floor space use in Chattanooga attracts about twice as many person-trips to the CBD as sales floor space use. It will be remembered that in the Gainesville study "service" floor space use was not a significant attractor of total trips. This apparent anomaly is explained by the fact that the Chattanooga "service" floor space classification is a broad one, including space used for office and public functions.

Total trip models for Chattanooga were also developed in terms of vehicle-trips. These models, shown subsequently as equations (6) and (7), are similar to equations (4) and (5), respectively, except that traffic flow to the CBD is expressed as vehicle trips rather than person-trips.

$$V_t = 4.95X_s + 10.24X_r + 5.44X_c - 111 \quad . \tag{6}$$

$$V_t = 3.30X_s + 12.69X_r + 305 \quad . \tag{7}$$

Equations (6) and (7) are described in more detail in Appendix C.

<u>The Effect of City Population on Total Traffic Models</u>

In order to provide a basis for comparing the results of their analysis of different cities, Harper and Edwards[2] related person-destinations to the CBD to three common floor space groups: (1) Retail; (2) Service-Office; and (3) Manufacturing-Warehousing. Typical floor space classifications included in these groups are shown by Table 2. Similar models were developed for Gainesville, Charlotte, and Chattanooga, providing a measure of the influence of city size on the Harper-Edwards model. These models, along with those developed by Harper and Edwards, are shown in Table 3. (See also Tables 17, 18, and 19, Appendix C.)

A study of the equations shown in Table 3 was made to determine if the regression coefficients are significantly related to population. A coordinate plot of the retail coefficients and urban area population suggested that the Retail coefficient, b_1, increased with increases in city population. A best-fit of a straight line to this data, shown as equation (8), strengthened this belief.

$$b_1 = 0.00108 \text{ (Population, Thousands)} + 11.19 \quad . \qquad (8)$$

With an F Ratio 118.23, equation (8) was significant at the 0.1 per cent level. This implies that the probability of obtaining equation (8) strictly by chance is less than 0.001. However, the small correlation coefficient of 0.49 indicates that much of the variation in the regression coefficient is not explained by equation (8). Indeed, this correlation coefficient is not significantly different from zero when tested at the five per cent level.

The hypothesis that the "true" regression coefficient for equation (8) is equal to zero was tested by Student's "t"-test. It was found that

Table 2. Typical Floor Space Classifications Included in Groups Used by Harper and Edwards[2]

Retail X_1	Service-Office X_2	Manufacturing-Warehousing X_3
Retail	Business Service	Manufacturing
Retail Business	Consumer Service	Wholesale with Stocks
Core Retail	Office Buildings	Warehouses
Intensive Retail	Public Offices	Light Industry
Extensive Retail	Bank and Miscellaneous	Heavy Industry
Open Business	Institutions	Industrial
	Wholesale without Stocks	Wholesaling
	Utilities	
	Hotels	
	Terminals	
	Parking Garages	
	Quasi-Public	
	Eating Places	
	Amusement	
	Recreation	

Table 3. Models for Nine Cities Relating Total Person Destinations to the CBD to Retail, Service-Office, and Manufacturing-Warehousing Floor Space Use

City	Population	Model
Gainesville	16,787	$Y_t = 10.95X_1 + 15.96X_2 - 3.30X_3 + 284$
Charlotte	202,000	$Y_t = 10.84X_1 + 13.83X_2 + 1.61X_3 + 1095$
Chattanooga	283,170	$Y_t = 8.49X_1 + 7.63X_2 - 2.92X_3 - 1168$
Tacoma	275,876	$Y_t = 7.71X_1 + 2.49X_2 - 17.70X_3 + 3590$
Vancouver	600,000	$Y_t = 14.32X_1 + 10.53X_2 + 3.67X_3 + 1560$
Dallas	614,799	$Y_t = 16.19X_1 + 3.55X_2 + 12.65X_3 - 8570$
Seattle	732,992	$Y_t = 13.68X_1 + 4.38X_2 + 0.15X_3 - 200$
Baltimore	1,337,373	$Y_t = 12.87X_1 + 4.52X_2 + 1.34X_3 - 1080$
Detroit	3,016,197	$Y_t = 13.92X_1 + 4.61X_2 + 1.72X_3 - 2280$
Phildelphia	3,671,048	$Y_t = 14.60X_1 + 5.86X_2 + 1.28X_3 - 3470$

the regression coefficient of 0.00108 was not significant at the 10 per cent level. Thus, it cannot be confidently asserted that the increases in the retail coefficients in Table 3 are associated with increases in population.

A plot of population versus the Service-Office coefficients in Table 3 suggested that the coefficients decrease with logarithmic increases in population. A least squares "best-fit" of the data yielded equation (9).

$$b_2 = 20.24 - 2.07 \text{ Ln (Population, Thousands)} \quad . \qquad (9)$$

According to this relationship, the Service-Office coefficient decreases sharply with increases in population up to about one million, beyond which b_2 decreases but at a diminishing rate. The regression coefficient of 2.07 in equation (9) was significant at the 5 per cent level.

Equation (9) was significant at the 0.1 per cent level, indicating that this apparent relationship would be expected purely by chance only once in 1,000 times if there is no relationship between the variables. However, a small correlation of 0.69 indicates that much of the variation in b_2 remains unexplained by the equation.

Attempts to relate the Manufacturing-Warehousing coefficients to city population indicated that this coefficient is not significantly related to city size. Neither was the constant (or zero-intercept) term of the models in Table 3 significantly related to population.

The significance of equations (8) and (9) suggest that it might be possible to develop a predictive model for a city based only on city population. This would mean that approximations of future CBD traffic could be made without reliance on costly origin-destination surveys. However, such a model would be influenced by the Manufacturing-Warehousing coefficient which, according to available evidence, is not significantly related to city size. That is to say, one cannot in this way estimate the Manufacturing-Warehousing coefficient with confidence.

It is important to point out that Manufacturing-Warehousing floor space use in the CBD is not closely related to traffic destinations. Of the ten Manufacturing-Warehousing coefficients shown in Table 3, only two are significant, even at the twenty per cent level. In short, Manufacturing-Warehousing floor space in the CBD does not have a significant effect on the regression model. With this in mind, models were developed relating only Retail and Service-Office floor space to total person-trips attracted to the CBD. These models are shown in Table 4. (See also Appendix C.)

The omission of the Manufacturing-Warehousing variable did not appear to have a harmful effect upon the predictive value of the models. In fact, the simpler three dimensional model in several cases appeared to be superior to the Harper-Edwards Model. A comparison of the standard errors and correlation coefficients of the models with and without the Manufacturing-Warehousing variable is shown as Table 5.

Utilizing the regression coefficients in the three dimensional models shown in Table 4, relationships were developed between population and the Retail and Service-Office coefficients. These relationships, which are given below, are comparable to equations (8) and (9).

Table 4. Models for Nine Cities Relating Total Person Destinations to the CBD to Retail and Service-Office Floor Space Use

City	Population	Model
Gainesville	16,787	$Y_t = 10.96X_1 + 16.48X_2 + 171$
Charlotte	202,000	$Y_t = 9.89X_1 + 15.68X_2 + 1404$
Chattanooga	283,170	$Y_t = 8.89X_1 + 7.31X_2 - 1388$
Tacoma	275,876	$Y_t = 6.20X_1 + 7.22X_2 - 1049$
Vancouver	600,000	$Y_t = 15.38X_1 + 9.76X_2 + 3898$
Dallas	614,799	$Y_t = 6.89X_1 + 4.86X_2 + 1475$
Seattle	732,992	$Y_t = 13.66X_1 + 4.35X_2 - 129$
Baltimore	1,337,373	$Y_t = 12.81X_1 + 4.52X_2 - 75$
Detroit	3,016,197	$Y_t = 13.50X_1 + 4.78X_2 - 380$
Philadelphia	3,671,048	$Y_t = 15.08X_1 + 5.93X_2 - 2584$

Table 5. A Comparison of the Standard Errors and Correlation Coefficients of the Harper-Edwards Models with Models for which the Manufacturing-Warehousing Coefficient Has Been Omitted

	Standard Error		Correlation Coefficient	
	Model with X_3	Model without X_3	Model with X_3	Model without X_3
Gainesville	870	833	0.889	0.885
Charlotte	801	729	0.999	0.997
Chattanooga	1,133	1,063	0.996	0.995
Tacoma	80	743	0.998	0.992
Vancouver	3,920	4,251	0.982	0.975
Dallas	4,420	5,367	0.959	0.927
Seattle	1,590	1,512	0.983	0.982
Baltimore	5,630	5,198	0.817	0.821
Detroit	2,890	3,071	0.998	0.998
Philadelphia	5,490	5,570	0.980	0.979

$$b_1 = 0.00150 \text{ (Population, Thousands)} + 9.72 \quad . \qquad (10)$$

$$b_2 = 22.61 - 2.33 \text{ Ln (Population, Thousands)} \quad . \qquad (11)$$

Plots of these functions are shown in Figures 8 and 9.

Correlation coefficients for equations (10) and (11) were, respectively, 0.57 and 0.79. Both models were significant at the 0.1 per cent level.

The regression coefficient of 0.00150 in equation (10) is significant at the 10 per cent level, while the regression coefficient of 2.33 in equation (11) is significant at the one per cent level. Thus, it can be asserted with confidence that the Service-Office coefficients shown in Table 4 decrease with logarithmic increases in city population. It can be similarly stated, but with less confidence, that the Retail regression coefficients increase with increases in population.

An attempt to relate the zero intercept or "constant" term of the equations in Table 4 to city population resulted in equation (12).

$$K = 844 - 0.66 \text{ (Population, Thousands)} \quad . \qquad (12)$$

However, equation (12) was not statistically significant and had a correlation coefficient of only 0.46. Correlation statistics for the model indicate that the zero intercept in the three dimensional models of Table 4 is not linearly related to city population. It should be pointed out that the wide variability of the zero intercept values is not as critical as one might suspect. This term, which represents the attraction of traffic to a zone having zero floor space, has little effect on predicted traffic values. Its relative effect is particularly small for the zones which attract high traffic volumes.

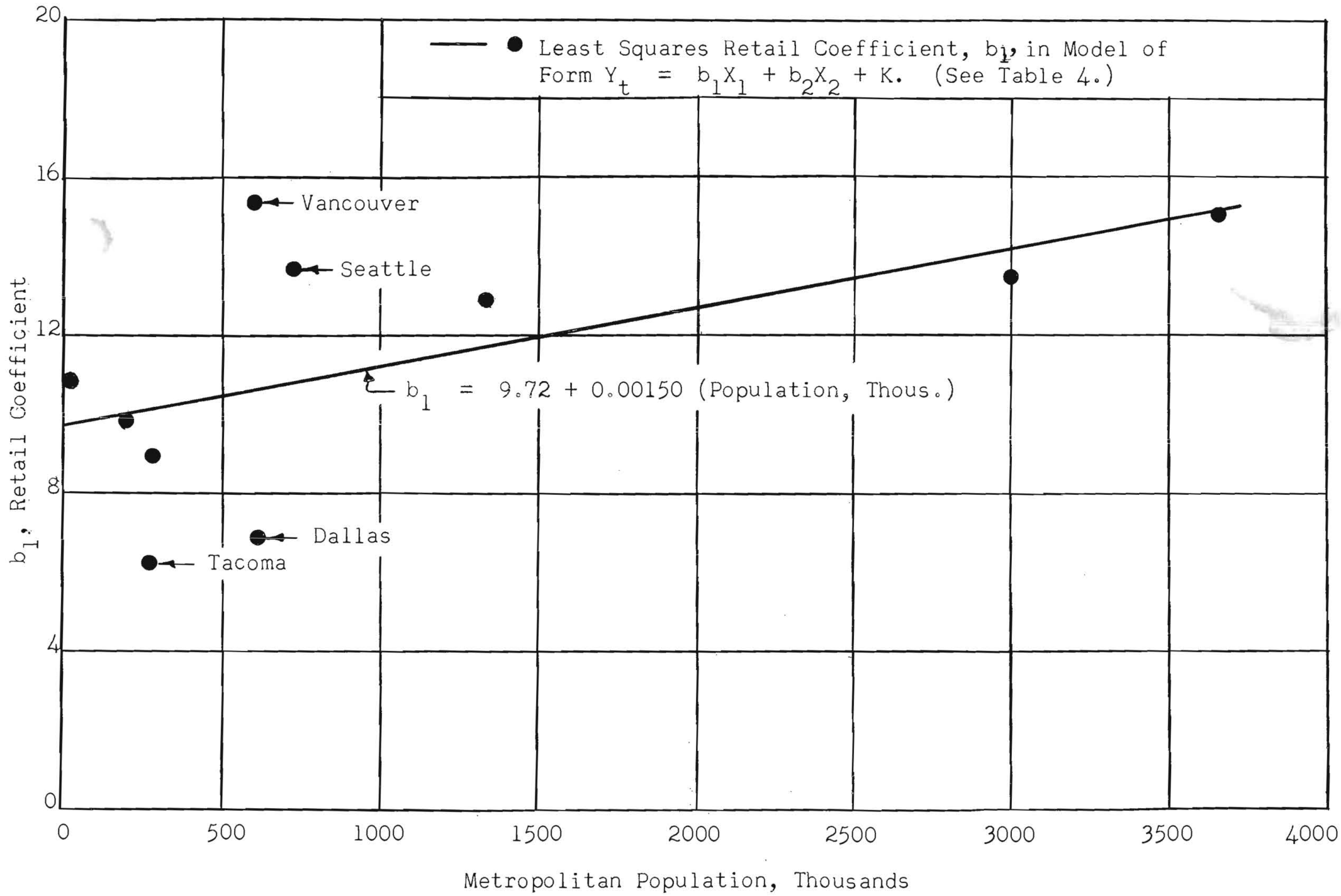

Figure 8. The Relationship of Retail Coefficients to City Population

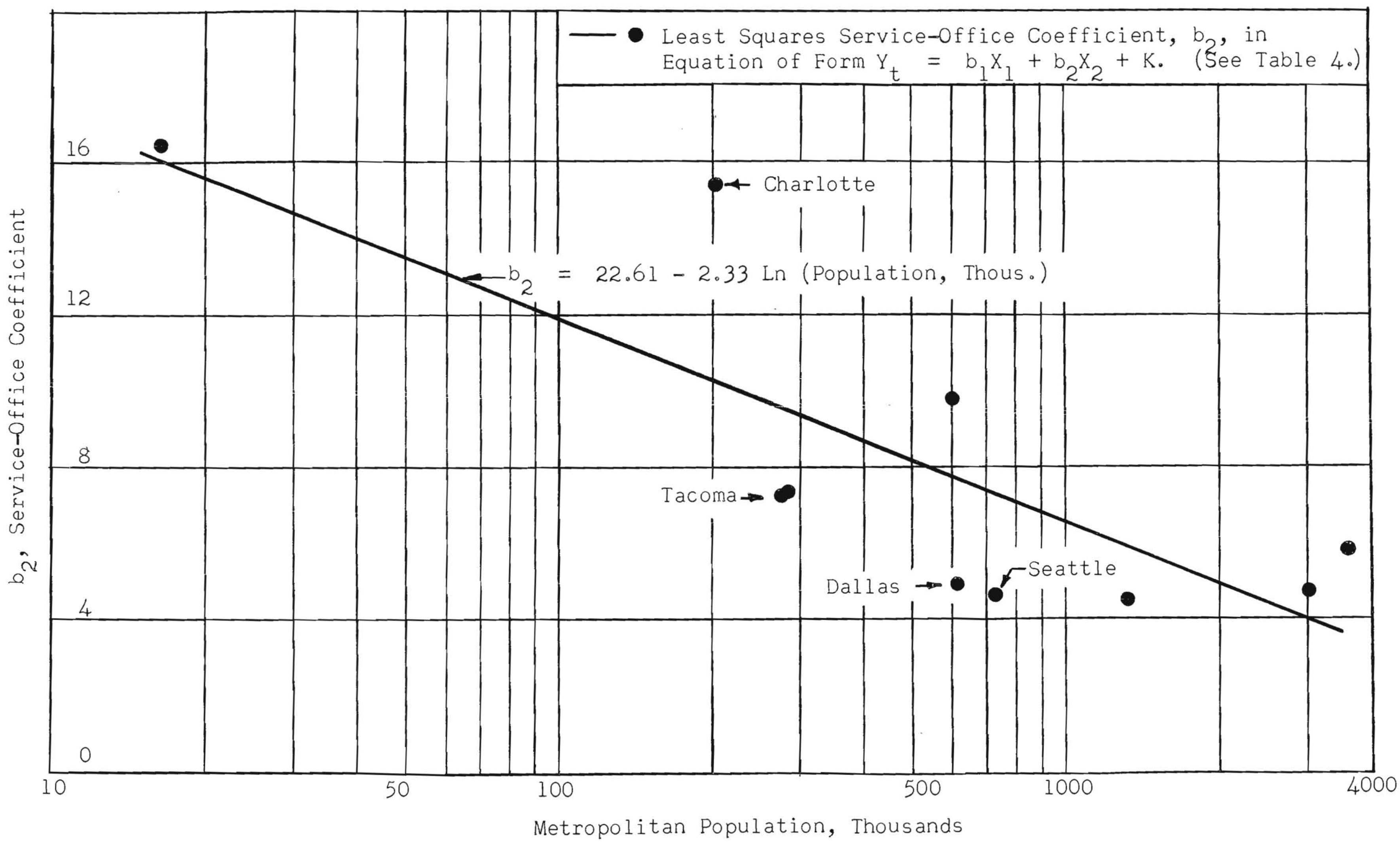

Figure 9. The Relationship of Service-Office Coefficients to City Population.

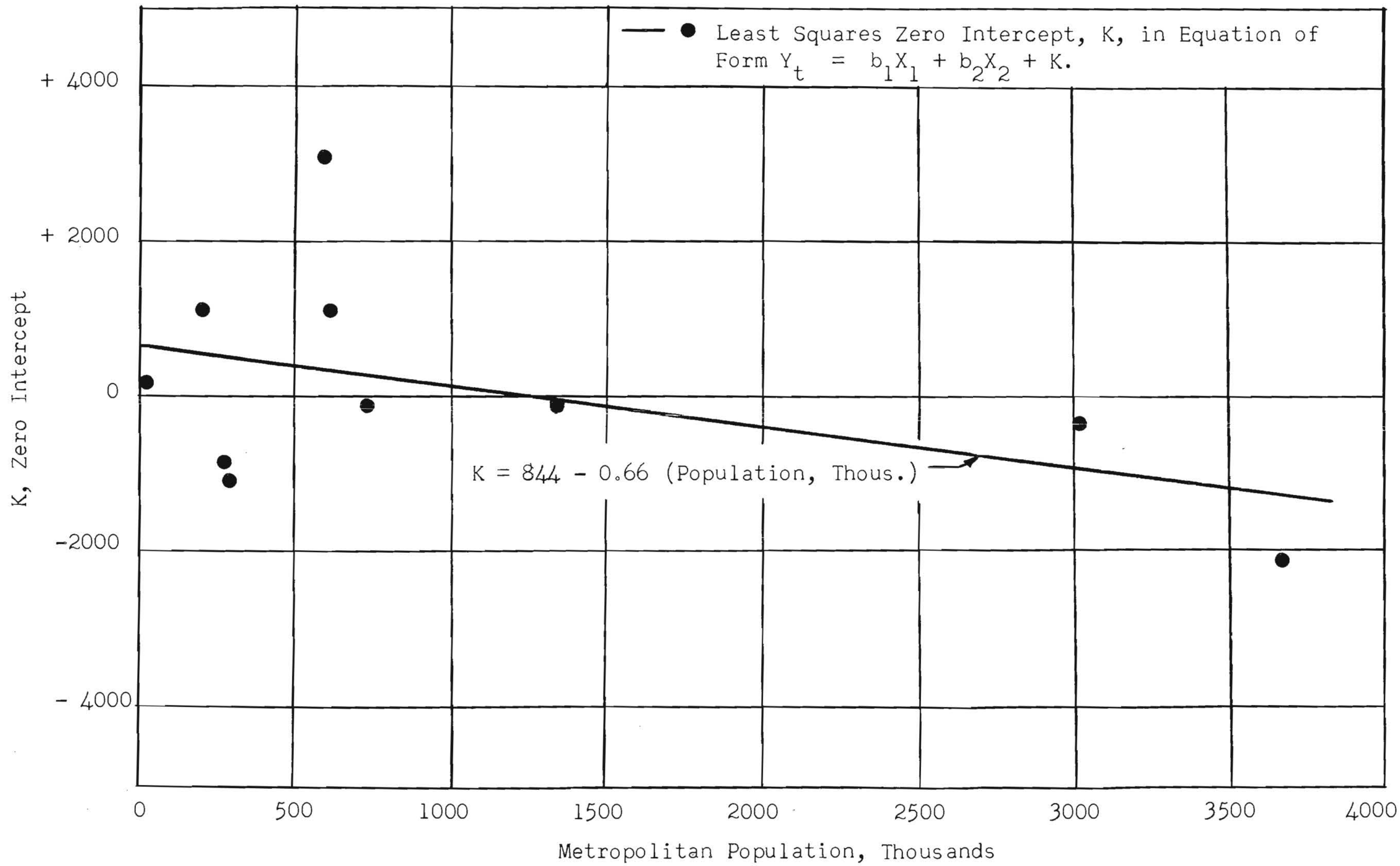

Figure 10. The Relationship of Zero Intercept Coefficient to City Population.

In summary, it can be stated with confidence that models of the type given in Tables 3 and 4 exhibit variations which can, in part at least, be explained by differences in population. The results show that the attraction of retail floor space to CBD trips increases slightly with increases in population. The relationship appears to be linear. In contrast, the "attractive power" of service-office floor space seems to decrease with logarithmic increases in city population.

In attempting to develop a predictive model for a particular city, it is of concern that much of the variation in the regression coefficients is not explained by differences in urban population. This means that it would be extremely risky to develop and use a predictive model of the type shown in Table 4 based on population alone.

Part of the deviation from the least squares line is caused by undertainties in the original models. The regression coefficients in these models may be thought of as only estimates of the "true" coefficients, and the reliability of the estimated coefficients depend on the number of observations or zones from which they were estimated.

To illustrate the effect that the number of zones has on the computed regression coefficients, models were developed for the city of Pittsburgh using the data grouped into 5, 10, and 59 "zones." As illustrated in Table 6, it was found that the regression coefficients varied widely depending on the number of observations or zones. The division of the CBD into small homogeneous zones results in a better stratification of the data which accounts for the differences in the regression coefficients. It is of particular interest that as the size of zones is decreased and as the reliability increases, the regression coefficients appear to approach the values that one would expect from a consideration of city population and the relationships previously developed (Figures 8, 9, and 10).

Table 6. The Influence of the Number of Observations on the Regression Coefficients in a Three Dimensional Linear Model -- Pittsburgh, Pennsylvania

Number of Observations or Zones	Model	F Ratio	Correlation Coefficient	Standard Error
5	$Y_t = -2.25X_1 + 17.78X_2 - 22{,}698$	27.85	0.9611	8707
10	$Y_t = 8.25X_1 + 8.13X_2 - 3{,}057$	42.67	0.9225	5057
59	$Y_t = 12.43X_1 + 5.50X_2 - 264$	161.52	0.9102	1336
Model "Expected" By Equations (10), (11), and (12)	$Y_t = 13.33X_1 + 4.47X_2 - 743$			

While a certain portion of the variation in the regression coefficients of the models in Table 4 is random and related to the uncertainties of the basic models, there are certain indicators which suggest that a great deal of the difference in the models may be explained in future research by measurable characteristics of the city such as retail business and service activities, employment, and location and attractiveness of competing centers.

It was noted, for example, that the coefficients for Charlotte and Chattanooga were marked by important differences even though the cities are of approximately the same size. A comparison of certain economic measures of city vitality seems to mirror the differences which were noted in the traffic models. For example, the larger Retail coefficient obtained in the Charlotte model can probably be explained in part by a consideration of the data presented in Table 7. Charlotte, which had a higher retail coefficient exhibited higher per capita sales and a larger number of retail establishments per capita. In 1954, Charlotte ranked 67th by volume of retail sales, while Chattanooga ranked 75th.[22]

The larger Service-Office coefficient was similarly reflected in the total receipts for "selected services" as shown in Table 8.

It is hypothesized that a substantial portion of the variation of certain of the regression coefficients is due to the proximity of competing centers. For example, as indicated in Table 4, low Retail and Service-Office coefficients were noted for Tacoma. Present knowledge of urban travel characteristics dictates that these values were influenced by the larger Seattle CBD which lies only about thirty miles away. There is also reason to believe that the low regression coefficients in the

Table 7. Measures of Retail Activities for the Cities of Charlotte and Chattanooga

City	Retail Coefficient b_1	Per Capita Retail Sales ($1,000)	Number of Retail Establishments Per 1000 Population
Charlotte	9.89	$1,827	8.33
Chattanooga	8.89	1,695	7.39
Ratio, Char./Chatt.	1.11	1.08	1.13

Source: U. S. Census of Business: 1954, Volume II, Bureau of the Census, Washington, 1956.

Table 8. Measures of Service-Office Activities for the Cities of Charlotte and Chattanooga

City	Service-Office Coefficient b_2	Total Receipts For Selected Services*	1960 Employment in Finance, Insurance and Real Estate
Charlotte	15.68	$50,220,000	5,287
Chattanooga	7.31	29,916,000	2,362
Ratio, Char./Chatt.	2.14	1.68	2.24

Sources: U. S. Census of Business: 1954, Volume VI, Bureau of the Census, Washington, 1957; and County and City Data Book prepared under direction of Edwin O. Goldfield, U. S. Government Printing Office, 1962.

*Note: "Selected Services," a term employed by the Bureau of the Census, includes Personal Services (e.g., barber shops, laundries, etc.); Business Services (e.g., advertising agencies, duplicating and mailing services, etc.); Auto Repair Services; Miscellaneous Repair Services; Amusement and Recreation Services; and Hotels, Motels, Tourist Courts, and Camps.

Dallas model may be partially explained by the competition of the Fort Worth CBD which is located only 30 miles away.

In summary, the results indicate that the construction of a total trip model from a consideration of population alone could lead to intolerable errors. Similarly, the application of a total trip model like those in Table 4 to another city of like size would be unwise. Either course of action would fail to take into consideration important values such as social, economic, and spatial considerations which remain unquantified.

Work Trip Models

Satisfactory work trip models were developed for Gainesville, Chattanooga, and Pittsburgh, and the results indicated that work trips are most closely related to public, service, and sales floor space use.

Work Trip Model for Gainesville, Georgia

Work trips to the Gainesville CBD are most closely related to service, office, and public floor space use. A least squares model relating these variables is shown as equation (13).

$$Y_w = 6.33X_r + 2.61X_o + 19.88X_p + 67 \qquad (13)$$

With an F Ratio of 42.97, this model was significant at the 0.1 per cent level. Its correlation coefficient was 0.940. Generally close agreement between the observed work trips and those computed with the model may be observed in Table 31, Appendix D.

For this model, the public floor space variable was most significant (0.1 per cent level). Its partial correlation coefficient was 0.890. Public floor space also had the largest regression coefficient. The model suggests that public floor space attracts about three times as many work trips per unit area as service floor space and nearly eight times as many as office floor space.

The service regression coefficient was significant at the one per cent level. The partial correlation coefficient for this variable was 0.791. The office floor space variable was significant at the five per cent level and had a partial correlation coefficient of 0.677.

Work trips to the Gainesville CBD did not appear to be closely related to sales, wholesale, manufacturing, or semi-public floor space use.

Work Trip Model for Chattanooga, Tennessee

For Chattanooga, a very satisfactory model was computed which relates vehicle work trips to the CBD to floor space used for retail sales and personal and business services.

$$V_w = 0.72X_s + 5.93X_r + 158 \quad . \tag{14}$$

The very high correlation coefficient (0.9987) for this model indicates that 99 per cent of the variation in work trips is explained by variations in floor space use. With an F Ratio of 799.59, the model is significant at the 0.1 per cent level. A zone-by-zone comparison of observed work trips and those computed with equation (14) is given in Table 33, Appendix D.

According to the Chattanooga model, vehicle work trips were most closely related to service floor space use. The service regression coefficient was significant at the 0.1 per cent level. The partial correlation coefficient for this variable was 0.994. The large service regression coefficient suggests that more than eight times as many vehicle work trips are attracted by Chattanooga's service floor space use per unit area as are attracted by sales floor space use. However, since the model was developed from only six observations or zones, this conclusion cannot be held with a high degree of confidence.

The retail sales regression coefficient was not highly significant, being significant at the 6 per cent level. However, its partial correlation coefficient was 0.869.

Work Trip Model for Pittsburgh, Pennsylvania

Work trips to Pittsburgh's central business district evidenced a close relationship to retail and public floor space use. A multiple regression model relating these variables is shown as equation (15).

$$Y_w = 8.29X_s + 14.44X_p + 290 . \qquad (15)$$

This equation was characterized by very satisfactory correlation statistics as were the regression coefficients. The model was significant at the 0.1 per cent level. The coefficient of multiple determination indicated that more than 96 per cent of the variation in traffic is explained by the model. For the seven most heavily travelled zones, computed traffic values varies less than 15 per cent from the observed values. These data are shown in Table 34.

Attempts to develop other work trip models indicated that work trips to Pittsburgh's CBD are not significantly related to heavy commercial, manufacturing, and service floor space use.

Shopping Trip Models

In the models which follow, shopping trips were found to be linearly related to sales, office, and public floor space use. However, the most satisfactory models were non-linear equations relating shopping trips and retail floor space use.

Shopping Trip Models for Gainesville, Georgia

In equation (16), shopping trips to the Gainesville CBD are related to sales, office, and public floor space use.

$$Y_s = 3.05X_s + 4.52X_o + 17.67X_p - 80 \quad . \tag{16}$$

From a statistical viewpoint, this model is satisfactory. It is characterized by a high correlation coefficient and high significance. Each of the independent variables is significant at the one per cent level; and each partial correlation coefficient exceeds 0.80. However, intuitively, one would question the value of the model. It is contrary to intuition that shopping trips are attracted by office and public floor space. The apparent correlation between shopping trips and public and office floor space use may be explained by a consideration of the shopping habits of CBD shoppers.

A special report of the Highway Research Board[23] states: "Though the majority of shopping trips originate at home, the downtown worker represents an important 'captive market' since up to a third of the shopping in the downtown area is done by persons already there as a result of employment." Recognition of the importance of the so-called captive market by entrepreneurs probably results in the location of certain shopping facilities in close proximity to places of employment. Office and public floor space, then, are probably directly related to sales floor space which in turn is directly related to shopping trips.

Intuitively, one would expect shopping trips to be directly related only to retail sales floor space use. It was found, however, that the Gainesville data could not be satisfactorily fitted to a simple two dimensional linear model. Several attempts were therefore made to develop non-linear models relating shopping trips and retail floor space use, one result of which was the second degree model shown as equation (17).

$$Y_s = -0.030X_s^2 + 13.78X_s - 148 \quad . \tag{17}$$

Although equation (17) as a whole exhibited satisfactory correlation statistics, the second degree term was not significant at the five per cent level.

Equation (18) is a least squares fit of the data for six of Gainesville's twelve zones and is weighted in favor of the most heavily travelled zones.

$$Y_s = 503.3 \text{ Ln } (X_s) - 1299 \quad . \tag{18}$$

This model suggests that shopping trips to Gainesville's most attractive zones are closely related to the natural logarithm of retail floor space use. Trips computed by equation (18) closely resemble the observed trips as evidenced by the small standard error.

Plots of equations (17) and (18) may be seem as Figure 11. Statistical data for these equations are given in Appendix E.

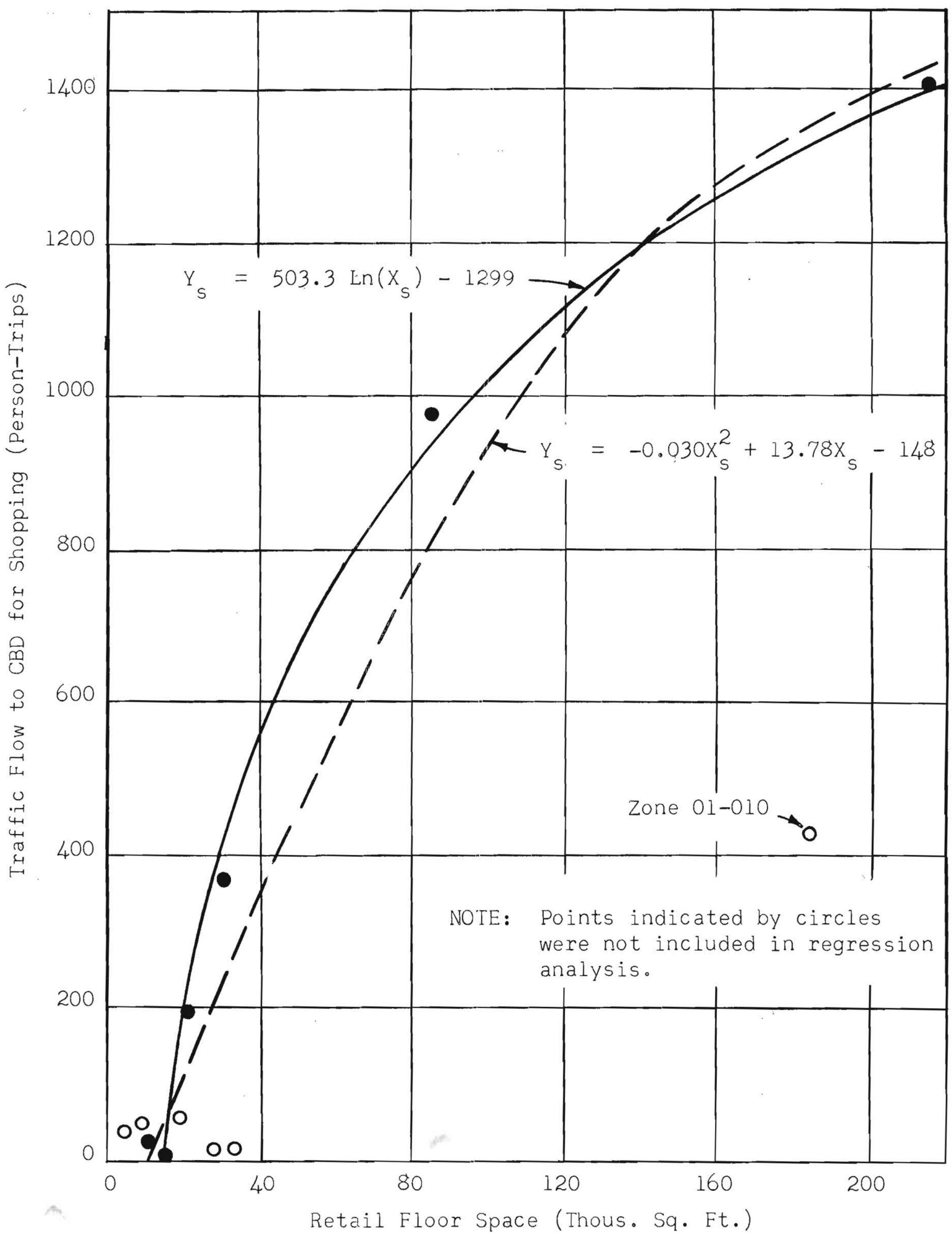

Figure 11. The Relationship of Shopping Trips to Gainesville CBD to Retail Floor Space Use.

In Figure 11, it will be observed that several of the zones in the Gainesville CBD had relatively large areas of retail floor space use, but exhibited little attractiveness to shopping trips. Examination of the type of floor space within these zones showed that these stores were inherently different from those which attracted large shopping trip volumes. Typical floor space uses included in the "sales" category for these zones were: service station; pawn shop; used cars; photo studio; auto accessories store; boat sales; drug stores; and small eating establishments.

The Gainesville data supports the thesis that shopping trips to certain retail floor space uses such as large department and variety stores are closely related to floor space area. In contrast, shopping trips to certain of Gainesville's smaller shops and establishments are only slightly related to floor space in use. Certain of these "retail" stores evidently attract few shopping trips, but depend on CBD employees and shoppers that are attracted to the larger stores.

It is evident from this study that more meaningful models could have been developed if a more detailed breakdown of "retail" floor space used had been provided. It would have been instructive, for example, to relate shopping trips to two sub-classifications of floor space use: one group including the major attractors of shoppers such as the large department and variety stores; and another group including all other retail uses.

Shopping Trip Models for Chattanooga, Tennessee

Shopping trips to Chattanooga's CBD were linearly related to retail and personal and business service floor space use. This relationship is shown as equation (19).

$$V_s = 2.27X_s + 0.53X_r - 154 \quad . \qquad (19)$$

Equation (19) was statistically significant at the 0.5 per cent level and had a correlation coefficient of 0.992. Its standard error was relatively small, indicating close agreement between the estimated and observed shopping trips to the six origin-destination zones. However, the personal and business service variable had a partial correlation coefficient of only 0.505 and was not significant at the five per cent level. A better model was obtained when shopping trips were related to retail floor space alone.

Attempts to develop non-linear models relating shopping trips and retail floor space produced the following second degree equation:

$$V_s = 0.00123X_s^2 + 0.992X_s + 26 \quad . \qquad (20)$$

With an F Ratio of 6033.55, equation (20) was highly significant. The correlation coefficient for the model was 0.999, and its standard error of estimate was only 26. For zones 511 and 513, where retail sales activity was highest, excellent agreement between the observed shopping trips and those computed with the model was noted. (See Table 41.) The model produced satisfactory estimates for the remaining zones. A graph of equation (20) along with observed data is shown as Figure 12.

<u>Shopping Trip Model for Pittsburgh, Pennsylvania</u>

Equation (21), a quadratic model relating shopping trips to the Pittsburgh CBD and retail floor space use, was highly significant.

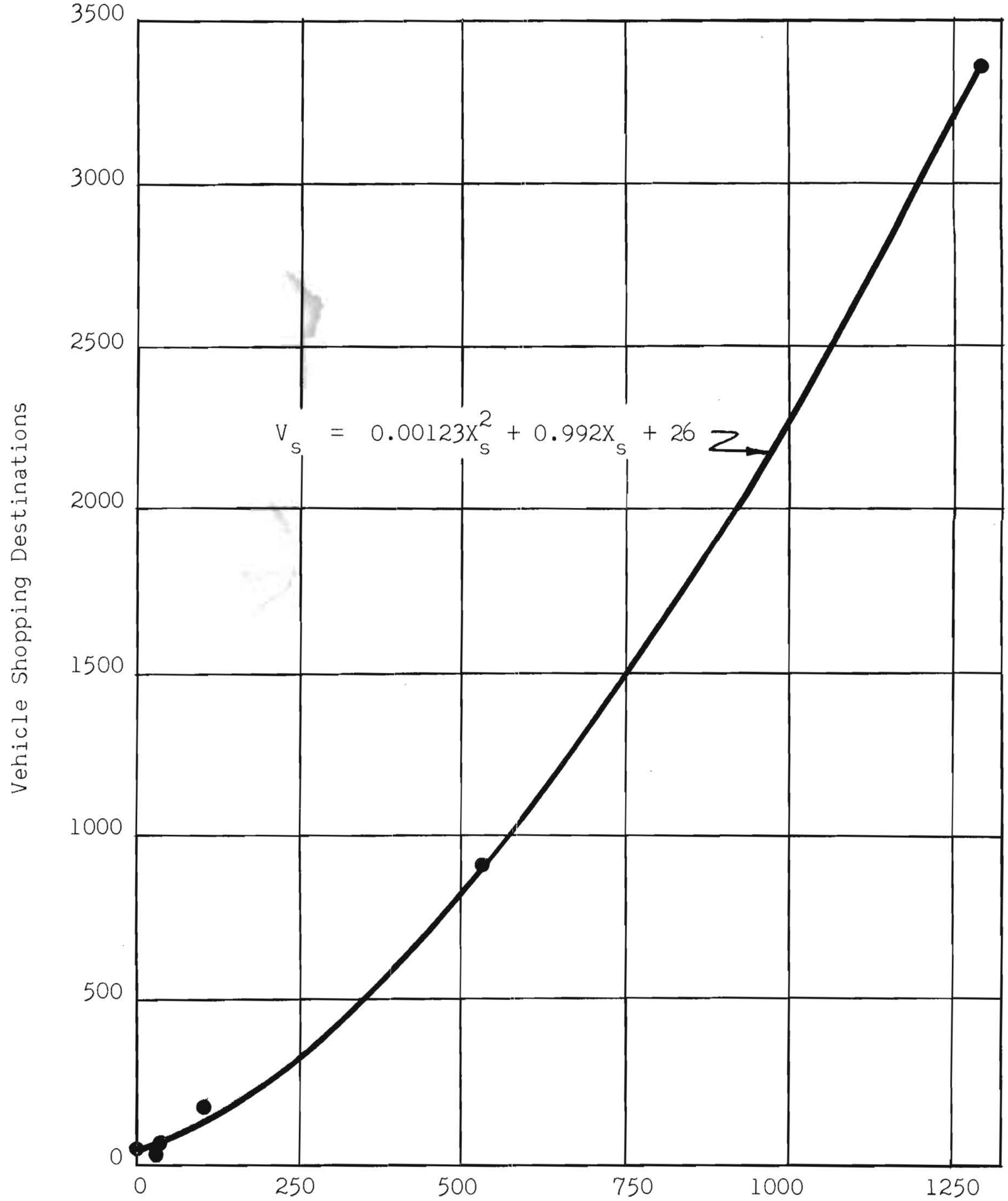

Figure 12. The Relationship of Shopping Trips to Chattanooga CBD to Retail Floor Space Use.

$$Y_s = 0.0112X_s^2 - 1.37X_s + 110 \quad . \tag{21}$$

Statistical data for this model are given in Table 42, Appendix E.

A plot showing equation (21) and the observed data is shown as Figure 13.

With a high correlation coefficient and a small standard error, equation (21) is statistically satisfactory. However, the linear term was negative and exhibited a very small partial correlation coefficient, suggesting that the "true" shopping model for Pittsburgh might take the form of a pure quadratic equation.

A linear model relating Pittsburgh shopping trips and retail and service floor space use was not significant at the one per cent level.

Personal Business Trip Models

For Gainesville and Chattanooga, respectively, personal business trips were found to be most closely related to office and service floor space use. In the Pittsburgh model, business trips were most closely related to sales and public floor space use.

Personal Business Trip Model for Gainesville, Georgia

The best personal business trip model for Gainesville was a four dimensional model including service, office, and public floor space use as the independent variables.

$$Y_b = 3.60X_r + 5.62X_o + 15.03X_p + 29 \quad . \tag{22}$$

Statistically, this model was less satisfactory than the work and shopping trip models for Gainesville. The model was significant at the 0.1 per cent level, but barely so. The correlation coefficient was only

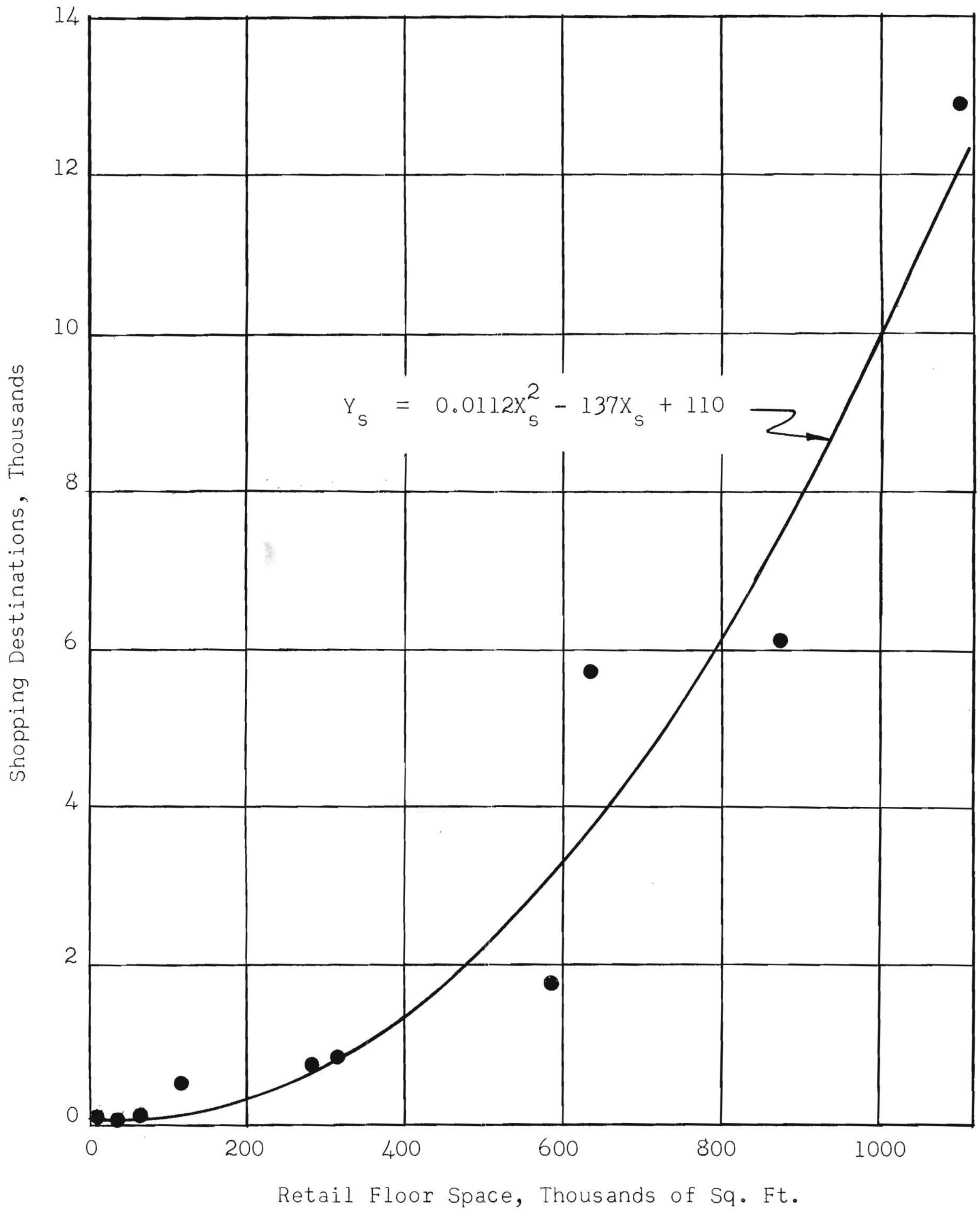

Figure 13. The Relationship of Shopping Trips to the Pittsburgh CBD to Retail Floor Space Use.

0.9089, implying that only about 82 per cent of the variation in business trips is associated with variations in floor space use. The computed business trips did not closely agree with the observed values, as indicated by the large standard error of estimate.

Business trips to the Gainesville CBD were most closely related to office floor space use. The office regression coefficient was significant at the one per cent level, and its partial correlation coefficient was 0.816. The public regression coefficient was significant at the five per cent level; its partial correlation coefficient was 0.725. The service regression coefficient was not significant at the five per cent level.

According to equation (22), public floor space use in Gainesville attracts about four times as many business trips as service use, and about 2.5 times as many as office use. Personal business trips to Gainesville were not significantly related to sales, wholesale, and semi-public floor space use.

Personal Business Trip Model for Chattanooga, Tennessee

Vehicle business trips to central Chattanooga were related to sales and service floor space use.

$$V_b = 0.37X_s + 1.42X_r + 83 \quad . \qquad (23)$$

While slightly less satisfactory from a statistical viewpoint than the work trip and shopping trip models, equation (23) is still highly satisfactory. The correlation coefficient for the model was 0.9929, and its standard error was 98. Equation (23) had an F Ratio of 152.12 and was significant at the 0.1 per cent level.

With a partial correlation coefficient of 0.959, the service regression coefficient was significant at the one per cent level. The retail sales variable was significant at the ten per cent level and had a partial correlation coefficient of 0.81.

The Chattanooga model suggests that nearly four times as many business trips are attracted to service floor space as to sales floor space.

Personal Business Trip Model for Pittsburgh, Pennsylvania

The best business trip model for Pittsburgh related business trips to the CBD to retail sales and public floor space use.

$$Y_b = 1.85X_s + 4.56X_p - 295 . \qquad (24)$$

This equation exhibited very satisfactory correlation statistics. The model was significant at the 0.1 per cent level, and its correlation coefficient was in excess of 0.97. Close agreement between the computed and observed traffic data was obtained, and the standard error of estimate was small. The variation between the computed and observed traffic values was ten per cent or less for six of the ten origin-destination zones. Very good statistical data for the regression coefficients was also noted.

Statistical data for equations (22), (23), and (24) is given in Appendix F.

Social and Recreation Trip Models

Predictive models for Gainesville, Charlotte, Chattanooga, and Pittsburgh social and recreation trips are included in Appendix G. However these models are consistently poor, and the results of this study indicates that social and recreation trips are not closely related to the area of floor space in use. Although several of these models produced satisfactory correlation statistics, certain of the regression coefficients were negative, casting doubt on the predictive value of these equations.

Summary of Results

In summary, thirteen regression equations, constituting the most satisfactory models which were developed, are shown in Table 9.

Table 9. A Summary of Results: Regression Models for the Cities of Gainesville, Charlotte, Chattanooga, and Pittsburgh

City	Model
	Total Trip Models
Gainesville	$Y_t = 8.98X_s + 21.12X_o + 63.26X_p + 216$
Charlotte	$Y_t = 10.62X_s + 9.29X_r + 15.01X_o + 2343$
Chattanooga	$Y_t = 7.30X_s + 13.56X_r + 7.02X_c - 25$
Pittsburgh	$Y_t = 13.30X_1 + 5.50X_2 - 743$
	Work Trip Models
Gainesville	$Y_w = 6.33X_r + 2.61X_o + 19.88X_p + 67$
Chattanooga	$V_w = 0.72X_s + 5.93X_r + 158$
Pittsburgh	$Y_w = 8.29X_s + 14.44X_p + 290$
	Shopping Trip Models
Gainesville	$Y_s = 503.3 \text{ Ln}(X_s) - 1299$
Chattanooga	$V_s = 0.00123X_s^2 + 0.992X_s + 26$
Pittsburgh	$Y_s = 0.0112X_s^2 - 1.37X_s + 110$
	Business Trip Models
Gainesville	$Y_b = 3.60X_r + 5.62X_o + 15.03X_p + 29$
Chattanooga	$V_b = 0.37X_s + 1.42X_r + 83$
Pittsburgh	$Y_b = 1.85X_s + 4.56X_p - 295$

CHAPTER VI

CONCLUSIONS

1. The number of people attracted to a zone within a city's central business district is closely related to the amount of floor space used for various purposes within that zone. The results of this study indicate that both total trips to the CBD and trips made for work, shopping, and business purposes are significantly related to the area of certain classifications of floor space use.

2. With but few exceptions, this research failed to show any significant relationships between social and recreation trips and the area of floor space use within the CBD.

3. Both total trips made to CBD zones and trips made for work, shopping, and business purposes are most closely related to the following floor space use classifications: retail sales, service, offices, and public use.

4. Traffic attracted to the central business district is not statistically related to manufacturing, wholesaling, and semi-public floor space use.

5. Regression coefficients in models of the type constructed in this study are critically affected by the size of origin-destination zones. The selection of small homogeneous zones tends to produce better stratification of the data and increases its reliability. In future origin-destination studies, it is therefore recommended that trips to the CBD be reported by a large number of homogeneous zones, preferably by city block.

6. In this research, significant regression models were constructed by relating traffic to only one or two classes of floor space use. In fact, the simpler two or three dimensional models frequenty exhibited better correlation statistics than those which included additional variables.

7. Wide variations of floor space use were noted within certain of the floor space classifications, impairing the usefulness of the models as means of estimating future traffic. These variations were especially noticeable for the retail variable for Gainesville which included such uses as: large department stores; used car lots; pawn shops; and small eating establishments.

8. In three-dimensional linear models relating total CBD person destinations and Retail and Service-Office floor space use, the retail regression coefficients increase linearly with city population. In these models, the Service-Office regression coefficients decrease with logarithmic increases in population. While the regression coefficients in these equations were significantly related to urban population, substantial deviations from the least square curves were noted, suggesting that it would be unwise to attempt to construct such a model based on urban area population alone or to apply one city's model to another of similar size.

9. In the four-dimensional linear model proposed by Harper and Edwards[2] in which total trips are related to Retail; Service-Office; and Manufacturing-Warehousing floor space use, the Manufacturing-Warehousing coefficient is not statistically significant.

10. There is a close relationship between the number of shopping trips to an area in the CBD and the amount of retail floor space in use within that section of the CBD. The results of this study indicate that the relationship between retail floor space use and shopping trips is non-linear.

11. The reliability of floor space models as a means of forecasting traffic depends on whether the regression coefficients remain constant with time. The effect of time on the regression coefficients was not tested in this research, but would be a profitable subject of future studies.

CHAPTER VII

RECOMMENDATIONS

1. The attainment of a basic understanding of the nature of CBD traffic is hindered by divergent and arbitrary methods of delimiting the central business district. A standard method of delimiting the central business district should be devised or agreed upon and used in future origin-destination studies. A scientific method of delimiting the CBD has been proposed by Murphy and Vance[7] and is worthy of consideration.

2. The problem of providing an efficient and adequate urban transportation system is complex. It is no longer sufficient, expecially in the case of large cities, to approach urban transportation needs on a piecemeal or fragmentary basis. Rather, intelligent planning of a city's future transportation facilities requires that the problem be viewed as a system, embracing all transportation modes. The planning of these facilities should therefore be concerned with the movement of people and goods rather than vehicles. The reporting of traffic in terms of person trips or person destinations would provide a more useful basis for transportation planning since plans made in this manner would be less affected by technological advances and changes in travel habits and customs. It is therefore recommended that in future origin-destination studies, travel to CBD zones be reported as person trips or person destinations in addition to vehicle trips or destinations.

3. The attainment of a full understanding of the relationships between CBD traffic and floor space use requires that more detailed traffic data be provided in origin-destination reports. Ideally, trips should be reported by city block as person trips or person destinations, and tabulations should be provided by trip purpose.

4. During the course of this study, it was observed that in contrast to large department and variety stores, certain "retail" floor space use exhibited little attractiveness to shopping trips. A more detailed breakdown of retail floor space use appears to be warranted by the results of the study. The classifications "extensive retail" and "intensive retail" have been used previously in certain floor space surveys, and such sub-classifications would probably add to the understanding of the relationships between shopping trips and "retail" floor space use.

5. For certain of the floor space classifications, a part of the variation in regression coefficients may be due to differences in intensity of floor space use. For example, overcrowding may have partially caused the remarkably high public regression coefficients for Gainesville. It is also likely that certain of the differences noted in the Retail and Service-Office regression coefficients for cities of different size are due to variations in intensity of floor space occupancy. It is therefore recommended that further research efforts be directed to developing measures of intensity of floor space use and attempting to quantify this variable. Some possible measures of intensity which may be fruitful areas of future study include: sales per square foot; employees per square foot; and average sales per customer.

6. The value of models such as those presented in this research as means of predicting future traffic is dependent on a knowledge of whether the regression coefficients remain constant with time. In future research, a long term comprehensive study of one or more cities is therefore recommended to measure the effect of time on the coefficients and to study the reasons for the variations which may be observed.

7. In developing traffic-floor space relationships for a given city, it should first be determined whether there exist any abnormalities in the intensity of floor space use and if there are extreme variations within the floor space classifications. Floor space classifications which evidence extreme conditions of underdevelopment or overcrowding would produce misleading regression coefficients and should therefore be omitted from the regression analysis. Broad floor space classifications which embrace a wide variety of uses would also tend to produce misleading results and should be excluded from the predictive models.

APPENDIX A

SAMPLE CALCULATIONS

In this Appendix the method for computing the regression coefficients and certain correlation statistics is illustrated. The illustrative calculations relate Shopping (person) Trips to the Gainesville central business district to Retail Sales and Office floor space use.

Traffic and Floor Space Data

Zone	Floor Space Use Sales X_s	Floor Space Use Office X_o	Traffic Y			
01-006	29.371	44.911	736	ΣX_s	=	659.03
01-010	184.060	7.194	853			
01-003	86.558	128.673	1953	ΣX_o	=	261.73
01-001	215.489	29.153	2814			
01-011	19.803	0	117	ΣX_s^2	=	91,939.79
01-004	8.686	26.607	103			
05-009	15.613	0	5	$\Sigma X_s X_o$	=	20,590.15
01-002	11.434	14.679	52			
01-007	20.221	1.000	398	ΣX_o^2	=	20,456.32
01-009	34.651	1.564	34			
01-005	4.950	7.328	80	ΣY	=	7,197
01-008	28.197	0.620	34			
				$\Sigma X_s Y$	=	968,519.03
Sum	659.033	261.729	7197			
Average	54.919	21.810	598	$\Sigma X_o Y$	=	377,088.18

Calculation of Regression Coefficients

For a three-dimensional model such as the one being developed, calculation of the regression coefficients involves the solution of three simultaneous equations:

$$b_0 n + b_1 \Sigma X_1 + b_2 \Sigma X_2 = \Sigma Y$$

$$b_0 \Sigma X_1 + b_1 \Sigma X_1^2 + b_2 \Sigma X_1 X_2 = \Sigma X_1 Y$$

$$b_0 \Sigma X_2 + b_1 \Sigma X_1 X_2 + b_2 \Sigma X_2^2 = \Sigma X_2 Y$$

This result generalizes for additional variables. For example, if one wished to predict traffic based on three floor space classifications, there would be four equations in the four unknowns b_0, b_1, b_2, and b_3 to solve.

Solution of these equations may be accomplished by matrix algebra as illustrated on the following page. From this solution,

$$b_0 \equiv K = -145.558$$

$$b_1 \equiv b_s = 9.035$$

$$b_2 \equiv b_o = 11.133$$

and the regression equation becomes

$$Y = 9.04X_s + 11.13X_o - 146 \quad .$$

CALCULATION OF REGRESSION COEFFICIENTS

By suitable matrix operations, the original matrix of the form F_1 will be transformed to the form F_2.

$$F_1 = \left[\begin{array}{ccc|c|ccc} n & \Sigma X_1 & \Sigma X_2 & \Sigma Y & 1 & 0 & 0 \\ \Sigma X_1 & \Sigma X_1^2 & \Sigma X_1 X_2 & \Sigma X_1 Y & 0 & 1 & 0 \\ \Sigma X_2 & \Sigma X_1 X_2 & \Sigma X_2^2 & \Sigma X_2 Y & 0 & 0 & 1 \end{array}\right] \qquad F_2 = \left[\begin{array}{ccc|c|ccc} 1 & 0 & 0 & b_0 & c_{00} & c_{01} & c_{02} \\ 0 & 1 & 0 & b_1 & c_{10} & c_{11} & c_{12} \\ 0 & 0 & 1 & b_2 & c_{20} & c_{21} & c_{22} \end{array}\right]$$

I_0	12.000	659.033	261.729	7,179.000	1	0	0	
II_0	659.033	91,939.790	20,590.152	968,519.030	0	1	0	←——ORIGINAL MATRIX
III_0	261.729	20,590.152	20,456.322	377,088.180	0	0	1	
								OPERATION
I_1	1	54.919	21.811	598.250	0.08333	0	0	$I_1 = I_0$ / 12.000
II_1	0	55,746.357	6,215.983	574,252.538	-54.919	1	0	$II_1 = II_0$ - 659.033I_1
III_1	0	6,216.257	14,747.751	220,508.806	-21.811	0	1	$III_1 = III_0$ - 261.729I_1
I_2	1	0	15.687	32.520	0.13743724	-0.000985158	0	$I_2 = I_1$ - 54.919II_2
II_2	0	1	0.11150473	10.301166	-0.000985158	0.000017938	0	$II_2 = II_1$ / 55,746.357
III_2	0	0	14,054.609	156,474.086	-15.687	-0.11150964	1	$III_2 = III_1$ - 6,216.257II_2
I_3	1	0	0	-145.558	0.1552930	-0.000858232	-0.001138255	$I_3 = I_2$ - 15.687III_3
II_3	0	1	0	9.035157	-0.000858237	0.0000188406	-0.000008090	$II_3 = II_2$ - 0.11150473III_3
III_3	0	0	1	11.13329	-0.001116146	-0.000007934	0.000071151	$III_3 = III_2$ / 14,054.609

b_0 = -145.558, b_1 = 9.035, b_2 = 11.133, c_{00} = 0.155293, c_{11} = 0.00001884, c_{22} = 0.00007115

Calculation of the Variance and Standard Error

Total Sum of Squares, SST $= \Sigma Y - n\bar{Y}^2$

$= 13{,}196{,}253.00 - 12(598.25)^2$

SST $= 8{,}879{,}852.25$

Regression Sum of Squares, SSR $= \Sigma bg - n\bar{Y}^2$

$- 145.558 \times 7179 = - 1{,}044{,}960.88$

$+ 9.035157 \times 968{,}519.03 = + 8{,}750{,}721.49$

$+ 11.13329 \times 377{,}088.18 = + 4{,}198{,}232.06$

$11{,}903{,}992.67$

$- 12(598.25)^2 \qquad - 4{,}316{,}400.75$

SSR $= 7{,}587{,}591.92$

Error Sum of Squares, SSE $=$ SST $-$ SSR

$= 8{,}879{,}852.25 - 7{,}587{,}591.92$

SSE $= 1{,}292{,}260.33$

$$\text{Variance, } S^2_{Y/X} = \frac{SSE}{n - (p + 1)}$$

$$\text{Variance, } S^2_{Y/X} = \frac{1{,}292{,}260.33}{12 - (2 + 1)} = 143{,}584.48$$

$$\text{Standard Error, } S_{Y/X} = \sqrt{\text{Variance}} = \sqrt{143{,}584} = 378.92$$

The F Test

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Regression	7,587,591.92	2	3,793,796.0	MSR/MSE = 26.42
Error	1,292,260.33	9	143,584.5	
Total	8,879,852.25	11		

The regression model is significant at the 0.1 per cent level, since $F_{0.001;2,9}$ is equal to 16.4.

Multiple Correlation Coefficient and Coefficient of Multiple Determination

Coefficient of Multiple Determination, $r^2 = \frac{\text{Regression Sum of Squares}}{\text{Total Sum of Squares}}$

$$= \frac{SSR}{SST} = \frac{7,587,591.92}{8,879,852.25}$$

$$r^2 = 0.854473$$

Multiple Correlation Coefficient, $r = \sqrt{0.854473}$

$$r = 0.9245$$

Standard Errors of the Regression Coefficients

$$s_{b_0} = s_{Y/X}\sqrt{c_{00}} = 378.92\sqrt{0.155293} = 149.32$$

$$s_{b_1} = s_{Y/X}\sqrt{c_{11}} = 378.92\sqrt{0.0000188406} = 1.645$$

$$s_{b_2} = s_{Y/X}\sqrt{c_{22}} = 378.92\sqrt{0.00007} = 3.196$$

Significance Tests for the Regression Coefficients

Null Hypothesis: "True" coefficients, $\beta_k = 0$, Alternative: $\beta_k \neq 0$, $k = 0,1,2$.

b_0: $t = \frac{-145.558}{149.32} = -0.9748$ Not Significant.

b_1: $t = \frac{9.035157}{1.645} = 5.4932$ Significant at 0.1 Per Cent Level.

b_2: $t = \frac{11.13333}{3.196} = 3.4835$ Significant at 1.0 Per Cent Level.

Simple and Partial Correlation Coefficients

Using the symbol Σ' to denote a summation of deviations from the means, the simple correlation coefficients are first computed. Thus, in the following calculations,

$$\Sigma(Y - \bar{Y})^2 \equiv \Sigma' Y^2 \quad ,$$

$$\Sigma(X_s - \bar{X}_s)(Y - \bar{Y}) \equiv \Sigma' X_s Y \quad \text{, and so forth.}$$

$$\Sigma' X_s X_o = \Sigma X_s X_o - \frac{(\Sigma X_s)(\Sigma X_o)}{n} = 20{,}590.15 - \frac{(659.03)(261.73)}{12}$$

$$= 6{,}215.98$$

$$\Sigma' X_s^2 = \Sigma X_s^2 - \frac{(\Sigma X_s)^2}{n} = 91{,}939.79 - \frac{(659.033)^2}{12}$$

$$= 55{,}746.36$$

$$\Sigma' X_o^2 = \Sigma X_o^2 - \frac{(\Sigma X_o)^2}{n} = 20{,}456.32 - \frac{(261.729)^2}{12}$$

$$= 14{,}747.75$$

$$\Sigma' YX_s = \Sigma YX_s - \frac{(\Sigma Y)(\Sigma X_s)}{n} = 968{,}519.03 - \frac{(7179)(659.033)}{12}$$

$$= 574{,}252.54$$

$$\Sigma' YX_o = \Sigma YX_o - \frac{(\Sigma Y)(\Sigma X_o)}{n} = 377{,}088.18 - \frac{(7179)(261.729)}{12}$$

$$= 220{,}508.81$$

$$\Sigma' Y^2 = \Sigma Y^2 - \frac{(\Sigma Y)^2}{n} = 13{,}196{,}253 - \frac{(7179)^2}{12}$$

$$= 8{,}879{,}852.25$$

Simple Correlation Coefficients

$$r_{X_sX_o} = \frac{\Sigma' X_sX_o}{\sqrt{\Sigma' X_s^2\ \Sigma' X_o^2}} = \frac{6215.98}{\sqrt{(55{,}746.36)(14{,}747.75)}} = 0.21678$$

$$r_{YX_s} = \frac{\Sigma' YX_s}{\sqrt{\Sigma' Y^2\ \Sigma' X_s^2}} = \frac{574{,}252.54}{\sqrt{(8{,}879{,}852)(55{,}746)}} = 0.8148$$

$$r_{YX_o} = \frac{\Sigma' YX_o}{\sqrt{\Sigma' Y^2\ \Sigma' X_o^2}} = \frac{220{,}508.81}{\sqrt{(8{,}879{,}852)(14{,}747)}} = 0.6092$$

Partial Correlation Coefficients

$$\text{for } b_s\text{:}\quad R_{YX_s} = \frac{r_{YX_s} - r_{X_sX_o}\ r_{YX_o}}{\sqrt{(1 - r^2_{YX_o})(1 - r^2_{X_sX_o})}}$$

$$= \frac{0.8148 - (0.21678)(0.6092)}{\sqrt{(1 - 0.6092^2)(1 - 0.21678^2)}} = 0.8814$$

$$\text{for } b_o\text{:}\quad R_{YX_o} = \frac{r_{YX_o} - r_{X_sX_o}\ r_{YX_s}}{\sqrt{(1 - r^2_{YX_s})(1 - r^2_{X_sX_o})}}$$

$$= \frac{0.6092 - (0.21678)(0.8148)}{\sqrt{1 - 0.8148^2)(1 - 0.21678^2)}} = 0.7626$$

The values computed herein are comparable to those shown in Table 36. It will be noted that the regression coefficients shown above are approximately twice those shown in Table 36, while the correlation statistics are the same. This is as expected since traffic data in the sample calculations was expressed in trip-ends, while the traffic data shown in Table 36 is expressed as destinations. The slight discrepancies between the values shown above and those shown in the table are apparently due to errors in rounding off.

APPENDIX B

FLOOR SPACE USE DATA

FLOOR SPACE USE DATA
Gainesville, Georgia

Thousands of Square Feet

O-D Zone	Sales	Service	Office	Wholesale	Manufacturing	Public	Semi-Public
01-006	29.371	23.493	44.911	0.000	0.000	9.600	0.000
01-010	184.060	75.443	7.194	21.390	4.495	0.000	0.000
01-003	86.558	10.624	128.673	2.400	0.000	12.723	37.755
01-001	215.489	13.127	29.150	0.000	21.244	34.500	0.500
01-011	19.803	2.668	0.000	55.089	1.328	12.000	0.000
01-004	8.686	7.360	26.607	0.000	22.600	0.000	30.824
05-009	15.613	17.890	0.000	126.505	19.200	0.000	0.000
01-002	11.434	13.318	14.679	12.914	8.940	0.000	0.000
01-007	20.221	2.560	1.000	1.220	2.400	0.000	0.000
01-009	34.651	10.297	1.564	7.400	0.000	0.000	0.782
01-005	4.950	0.000	7.328	0.000	0.000	0.000	0.000
01-008	28.197	6.007	0.620	0.000	0.000	8.500	3.640

(Continued)

FLOOR SPACE USE DATA (Continued)
Charlotte, North Carolina

Thousands of Square Feet

O-D Zone	Sales	Service	Office	Wholesale	Manufacturing	Public	Semi-Public	Parking Garages
6111	1,340.686	200.548	880.959	472.526	29.666	34.381	78.864	68.727
6112	226.814	253.044	93.613	119.397	6.166	22.003	7.980	0.000
6113	92.224	61.888	176.854	515.490	130.573	0.000	21.160	0.000
6114	168.620	55.678	481.226	591.871	171.650	0.000	14.501	0.000
6115	64.979	171.333	308.955	425.590	117.340	76.834	46.914	1.688

(Continued)

FLOOR SPACE USE DATA (Continued)
Chattanooga, Tennessee

	Thousands of Square Feet						
O-D Zone	Retail	P & B Service	Institutions	Wholesale	Industrial	Amusement	Hotel
511	1289.658	894.139	68.200	27.730	1.460	57.070	373.170
512	0.000	0.000	27.600	0.000	0.000	0.000	0.000
513	532.351	164.851	12.450	86.445	67.377	13.105	0.000
514	28.066	30.676	119.031	1.100	0.000	0.000	0.000
515	102.500	381.202	377.610	41.453	60.500	1.800	45.075
516	36.810	321.055	56.300	371.665	19.980	0.000	274.395

(Continued)

FLOOR SPACE USE DATA (Continued)
Pittsburgh, Pennsylvania

Thousands of Square Feet

O-D Zone*	Retail	Service	Heavy Commercial	Manufacturing	Utilities and Communications	Public Buildings
60-80	227.178	730.829	431.740	55.014	52.014	299.684
80-80	410.638	1412.221	780.543	258.473	87.592	209.700
40-60	1343.510	2169.607	29.746	5.559	349.333	223.915
60-60	1277.395	1517.891	27.083	105.239	9.498	61.107
80-60	1187.015	1400.416	15.305	122.191	556.506	49.092
40-40	107.142	509.433	716.711	401.447	0.000	103.721
60-40	575.344	1222.343	145.582	41.184	7.305	254.906
80-40	1268.451	2033.171	5.210	6.299	87.490	605.298
60-20	59.631	211.353	316.658	74.399	23.251	26.034
80-20	21.609	1025.818	37.081	278.753	96.982	308.037

*For the purposes of this study, the Pittsburgh data, which was obtained by city block, was regrouped into ten summary zones. The zone numbers refer to the X and Y coordinates used by the Pittsburgh Area Transportation Study and indicate the approximate location of these zones.

APPENDIX C

TOTAL TRIP MODELS

Table 10. Total Destinations Related to Sales, Office, Public Floor Space Use -- Gainesville, Georgia

REGRESSION EQUATION: $Y_t = 8.98X_s + 21.12X_o + 63.26X_p + 216,$

where Y_t = Computed response, 24-hour person destinations to CBD zone.

X_s = Area of floor space within zone used for retail sales.

X_o = Area of floor space within zone used for offices.

X_p = Area of floor space within zone used for public purposes.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Total Person Destinations	Observed Total Person Destinations
01-006	2,035	2,845
01-010	2,020	2,169
01-003	4,516	4,316
01-001	4,949	4,873
01-011	1,152	1,265
01-004	856	500
05-009	356	178
01-002	412	526
01-007	418	667
01-009	560	393
01-005	415	640
01-008	1,019	552

F Ratio = 90.82 Standard Error, $S(Y_t)$ = 398

Correlation Coefficient, R = 0.9778 r^2 = 0.956

Statistical Data for Regression Coefficients

	Sales b_s	Office b_o	Public b_p
Level of Significance	1%	0.1%	1%
Partial Correlation Coefficient	0.827	0.907	0.822
Standard Error	2.162	3.476	15.516

Table 11. Internal Destinations Related to Sales, Office, Public Floor Space Use -- Gainesville, Georgia

REGRESSION EQUATION: $Y_i = 4.74X_s + 14.48X_o + 29.07X_p + 94,$

where Y_i = Computed response, 24-hour person destinations from internal zones.

X_s = Area of floor space within zone used for retail sales.

X_o = Area of floor space within zone used for offices.

X_p = Area of floor space within zone used for public purposes.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Internal Person Destinations	Observed Internal Person Destinations
01-006	1,162	1,458
01-010	1,072	1,088
01-003	2,734	2,660
01-001	2,504	2,552
01-011	536	506
01-004	520	328
05-009	168	50
01-002	360	342
01-007	204	333
01-009	280	264
01-005	223	440
01-008	484	264

F Ratio = 136.03 Standard Error, $S(Y_i)$ = 180

Correlation Coefficient, r = 0.9856 r^2 = 0.971

Statistical Data for Regression Coefficients

	Sales b_s	Office b_o	Public b_p
Level of Significance	1%	0.1%	1%
Partial Correlation Coefficient	0.864	0.956	0.826
Standard Error	0.976	1.571	7.014

Table 12. Total Person Destinations Related to Retail, Service, Office Floor Space Use -- Charlotte, North Carolina

REGRESSION EQUATION: $Y_t = 10.62X_s + 9.29X_r + 15.01X_o + 2343$

where Y_t = Computed response, 24-hour person destinations to CBD zone.

X_s = Area of floor space within zone used for retail sales.

X_r = Area of floor space within zone used for services.

X_o = Area of floor space within zone used for offices.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Total Person Destinations	Observed Total Person Destinations
6111	31,667	31,616
6112	8,508	8,716
6113	6,552	6,387
6114	11,874	12,163
6115	9,260	8,970

F Ratio = 1391.26

Standard Error, $S(Y_t)$ = 491

Correlation Coefficient, r = 0.9997

r^2 = 0.99

Statistical Data for Regression Coefficients

	Retail b_s	Service b_r	Office b_o
Level of Significance	N.S.	N.S.	N.S.
Partial Correlation Coefficient	0.993	0.918	0.991
Standard Error	1.290	4.025	2.072

Table 13. Total Person Destinations Related to Retail, Personal, and Business Service, Institutions Floor Space Use -- Chattanooga, Tennessee

REGRESSION EQUATION: $Y_t = 7.30X_s + 13.56X_r + 7.02X_c - 25$,

where Y_t = Computed response, total 24-hour person destinations to CBD zone.

X_s = Area of floor space within zone used for retail sales.

X_r = Area of floor space within zone used for personal and business services.

X_c = Area of floor space with zone used for institutional purposes.

All floor space values are expressed in thousands of square feet.

O-D Zone	Observed Total Person Destinations	Observed Total Person Destinations
511	21,991	22,248
512	168	1,104
513	6,184	5,594
514	1,432	1,230
515	8,542	8,575
516	4,991	4,556

F Ratio = 204.62 — Standard Error, $S(Y_t) = 872$

Correlation Coefficient, $r = 0.9976$ — $r^2 = 0.995$

Statistical Data for Regression Coefficients

	Sales b_s	Service b_r	Institutional b_c
Level of Significance	N.S.	1%	N.S.
Partial Correlation Coefficient	0.945	0.962	0.798
Standard Error	1.792	2.728	3.748

Table 14. Total Person Destinations Related to Retail, Personal and Business Service Floor Space Use -- Chattanooga, Tennessee

REGRESSION EQUATION: $Y_t = 5.17X_s + 16.72X_r + 512,$

where Y_t = Computed response, 24-hour person destinations to CBD zone.

X_s = Area of floor space within zone used for retail sales.

X_r = Area of floor space within zone used for personal and business services.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Total Person Destinations	Observed Total Person Destinations
511	22,123	22,248
512	512	1,104
513	6,018	5,594
514	1,170	1,230
515	7,415	8,575
516	6,070	4,556

F Ratio = 147.91

Standard Error, $S(Y_t)$ = 1,181

Correlation Coefficient, r = 0.9932

r^2 = 0.986

Statistical Data for Regression Coefficients

	Sales b_s	P & B Service b_r
Level of Significance	N.S.	5%
Partial Correlation Coefficient	0.847	0.976
Standard Error	1.874	2.904

Table 15. Total Vehicle Destinations Related to Retail, Service, Institution Floor Space Use -- Chattanooga, Tennessee

REGRESSION EQUATION: $V_t = 4.95X_s + 10.24X_r + 5.44X_c - 111,$

where V_t = Computed response, 24-hour vehicle destinations to CBD zone.

X_s = Area of floor space within zone used for retail sales.

X_r = Area of floor space within zone used for personal and business services.

X_c = Area of floor space within zone used for institutional purposes.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Total Vehicle Destinations	Observed Total Vehicle Destinations
511	15,798	16,000
512	39	727
513	4,280	3,816
514	990	880
515	6,354	6,365
516	3,664	3,334

F Ratio = 189.82 Standard Error, $S(V_t)$ = 652

Correlation Coefficient, r = 0.9974 r^2 = 0.994

Statistical Data for Regression Coefficients

	Sales b_s	Service b_r	Institutional b_c
Level of Significance	N.S.	5%	N.S.
Partial Correlation Coefficient	0.934	0.962	0.808
Standard Error	1.328	2.022	2.778

Table 16. Total Vehicle Destinations Related to Retail, Personal and Business Service Floor Space Use -- Chattanooga, Tennessee

REGRESSION EQUATION: $V_t = 3.30X_s + 12.69X_r + 305$,

where V_t = Computed response, 24-hour vehicle destinations to CBD zone.

X_s = Area of floor space within zone used for retail sales.

X_r = Area of floor space within zone used for personal and business services.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Total Vehicle Destinations	Observed Total Vehicle Destinations
511	15,880	16,000
512	305	727
513	4,148	3,816
514	786	880
515	5,473	6,365
516	4,496	3,334

F Ratio = 130.97 Standard Error, $S(V_t)$ = 904

Correlation Coefficient, r = 0.9924 r^2 = 0.985

Statistical Data for Regression Coefficients

	Sales b_s	P & B Service b_r
Level of Significance	N.S.	5%
Partial Correlation Coefficient	0.799	0.957
Standard Error	2.434	2.222

Table 17. Total Person Destinations Related to Retail, Service-Office, and Manufacturing-Warehousing Floor Space Use -- Gainesville, Georgia

REGRESSION EQUATION: $Y_t = 10.95X_1 + 15.96X_2 - 3.30X_3 + 284,$

where Y_t = Computed response, 24-hour person destinations to CBD zone.

X_1 = Area of floor space within zone used for retail sales.

X_2 = Area of floor space within zone used for service-office purposes.

X_3 = Area of floor space within zone used for manufacturing-warehousing purposes.

All floor space values are expressed in thousands of square feet. Classifications are the same as those used by Harper and Edwards.

O-D Zone	Computed Total Person Destinations	Observed Total Person Destinations
01-006	1,665	2,845
01-010	1,718	2,169
01-003	4,252	4,316
01-001	3,806	4,873
01-011	549	1,265
01-004	1,338	500
05-009	260	178
01-002	784	526
01-007	550	667
01-009	840	393
01-005	455	640
01-008	892	552

F Ratio = 1740 Standard Error, $S(Y_t) = 870$

Correlation Coefficient, $r = 0.8889$ $r^2 = 0.790$

Statistical Data for Regression Coefficients

	Retail b_1	Serv.-Off. b_2	Mfg.-Whse. b_3
Level of Significance	1%	1%	N.S.
Partial Correlation Coefficient	0.674	0.698	- 0.175
Standard Error	4.243	5.784	6.564

Table 18. Total Person Destinations Related to Retail, Service-Office, and Manufacturing-Warehousing Floor Space Use -- Charlotte, North Carolina

REGRESSION EQUATION: $Y_t = 10.84X_1 + 13.83X_2 + 1.61X_3 + 1095$

where Y_t = Computed response, 24-hour person destinations to CBD zone.

X_1 = Area of floor space within zone used for retail sales.

X_2 = Area of floor space within zone used for service-office purposes.

X_3 = Area of floor space within zone used for manufacturing-warehousing purposes.

All floor space values are expressed in thousands of square feet. Classifications are the same as those used by Harper and Edwards.

O-D Zone	Computed Total Person Destinations	Observed Total Person Destinations
6111	31,679	31,616
6112	8,597	8,716
6113	6,468	6,387
6114	11,597	12,163
6115	9,515	8,970

F Ratio = 523.82 Standard Error, $S(Y_t)$ = 801

Correlation Coefficient, r = 0.9992 r^2 = 0.99

Statistical Data for Regression Coefficients

	Retail b_1	Service-Office b_2	Mfg.-Whse. b_3
Level of Significance	N.S.	N.S.	N.S.
Partial Correlation Coefficient	0.978	0.960	0.630
Standard Error	2.312	4.030	1.982

Table 19. Total Person Destinations Related to Retail, Service-Office, and Manufacturing-Warehouse Floor Space Use -- Chattanooga, Tennessee

REGRESSION EQUATION: $Y_t = 8.49X_1 + 7.63X_2 - 2.92X_3 - 1168$,

where Y_t = Computed response, 24-hour person destinations to CBD zone.

X_1 = Area of floor space within zone used for retail sales.

X_2 = Area of floor space within zone used for service-office purposes.

X_3 = Area of floor space within zone used for manufacturing-warehousing purposes.

All floor space values are expressed in thousands of square feet. Classifications are the same as those used by Harper and Edwards.

O-D Zone	Computed Total Person Destinations	Observed Total Person Destinations
511	21,795	22,248
512	264	1,104
513	6,606	5,594
514	1,458	1,230
515	9,138	8,575
516	4,045	4,556

F Ratio = 120.87   Standard Error, $S(Y_t)$ = 1,133

Correlation Coefficient, r = 0.9959 r^2 = 0.992

Statistical Data for Regression Coefficients

	Retail b_1	Service-Office b_2	Mfg.-Whse. b_3
Level of Significance	5%	5%	N.S.
Partial Correlation Coefficient	0.973	0.973	- 0.493
Standard Error	1.414	1.270	3.648

Table 20. Total Person Destinations Related to Retail, Service-Office Floor Space Use -- Gainesville, Georgia

REGRESSION EQUATION: $Y_t = 10.96X_1 + 16.48X_2 + 171,$

where Y_t = Computed response, 24-hour person destinations to CBD zone.

X_1 = Area of floor space within zone used for retail sales.

X_2 = Area of floor space within zone used for service-office purposes.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Total Person Destinations	Observed Total Person Destinations
01-006	1,620	2,845
01-010	3,550	2,169
01-003	4,246	4,316
01-001	3,760	4,873
01-011	630	1,265
01-004	1,330	500
05-009	637	178
01-002	758	526
01-007	451	667
01-009	759	393
01-005	346	640
01-008	894	552

F Ratio = 25.21 Standard Error, $S(Y_t)$ = 833

Correlation Coefficient, r = 0.8851 r^2 = 0.783

Statistical Data for Regression Coefficients

	Retail b_1	Service-Office b_2
Level of Significance	5%	5%
Partial Correlation Coefficient	0.669	0.710
Standard Error	4.065	5.450

Table 21. Total Person Destinations Related to Retail, Service-Office Floor Space Use -- Charlotte, North Carolina

REGRESSION EQUATION: $Y_t = 9.89X_1 + 15.68X_2 + 1404$,

where Y_t = Computed response, 24-hour person destinations to CBD zone.

X_1 = Area of floor space within zone used for retail sales.

X_2 = Area of floor space within zone used for service-office purposes.

All floor space values are expressed in thousands of square feet. Classifications are the same as those used by Harper and Edwards.

O-D Zone	Computed Total Person Destinations	Observed Total Person Destinations
6111	31,621	31,616
6112	9,083	8,716
6113	6,059	6,387
6114	11,491	12,163
6115	9,577	8,970

F Ratio = 842.31 Standard Error, $S(Y_t)$ = 729

Correlation Coefficient, r = 0.9987 r^2 = 0.99

Statistical Data for Regression Coefficients

	Retail b_1	Service-Office b_2
Level of Significance	5%	5%
Partial Correlation Coefficient	0.968	0.965
Standard Error	1.821	3.025

Table 22. Total Person Destinations Related to Retail, Service-Office Floor Space Use -- Chattanooga, Tennessee

REGRESSION EQUATION: $Y_t = 8.89X_1 + 7.31X_2 - 1388$,

where Y_t = Computed response, 24-hour person destinations to CBD zone.

X_1 = Area of floor space within zone used for retail sales.

X_2 = Area of floor space within zone used for service-office purposes.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Total Person Destinations	Observed Total Person Destinations
511	21,684	22,248
512	0	1,104
513	6,899	5,594
514	1,153	1,230
515	8,850	8,575
516	4,733	4,556

F Ratio = 182.86 Standard Error, $S(Y_t)$ = 1,063

Correlation Coefficient, r = 0.9945 r^2 = 0.989

Statistical Data for Regression Coefficients

	Retail b_1	Service-Office b_2
Level of Significance	1%	1%
Partial Correlation Coefficient	0.972	0.966
Standard Error	1.239	1.132

Table 23. Total Person Destinations Related to Retail, Service-Office Floor Space Use -- Tacoma, Washington

REGRESSION EQUATION: $Y_t = 6.200X_1 + 7.223X_2 - 1049$

where Y_t = Computed response, 24-hour person trips to CBD zone.

X_1 = Area of floor space within zone classified as retail.

X_2 = Area of floor space within zone classified as service-office.

All floor space values are in units of thousands of square feet.

O-D Zone	Computed Total Person Trips	Observed Total Person Trips
000	6,864	6,450
001	4,762	4,610
002	13,630	13,540
003	6,053	6,970
004	2,606	2,360

F Ratio = 180.53 Standard Error, S (Y_t) = 743

Correlation Coefficient, r = 0.9921 r^2 = 0.983

Statistical Data for Regression Coefficients

	Retail b_1	Service-Office b_2
Level of Significance	5%	N.S.
Partial Correlation Coefficient	0.972	0.947
Standard Error	1.058	1.710

Table 24. Total Person Destinations Related to Retail, Service-Office Floor Space Use -- Vancouver, British Columbia

REGRESSION EQUATION: $Y_t = 15.380X_1 + 9.760X_2 + 3898$,

where Y_t = Computed response, 24-hour person trips to CBD zone.

X_1 = Area of floor space within zone classified as retail.

X_2 = Area of floor space within zone classified as service-office.

All floor space values are in units of thousands of square feet.

O-D Zone	Computed Total Person Trips	Observed Total Person Trips
900	45,807	46,900
901	50,374	48,640
902	5,945	4,400
910	19,029	18,530
911	8,951	1,860
920	11,671	14,220
921	4,399	2,630
930	4,911	12,580
940	10,130	14,110
950	36,956	39,460
951	17,709	16,450

F Ratio = 132.45 Standard Error, $S(Y_t)$ = 4251

Correlation Coefficient, r = 0.9750 r^2 = 0.951

Statistical Data for Regression Coefficients

	Retail b_1	Service-Office b_2
Level of Significance	0.1%	0.1%
Partial Correlation Coefficient	0.893	0.925
Standard Error	2.745	1.421

Table 25. Total Person Destinations Related to Retail, Service-Office Floor Space Use -- Dallas, Texas

REGRESSION EQUATION: $Y_t = 6.889X_1 + 4.862X_2 + 1475,$

where Y_t = Computed response, 24-hour person trips to CBD zone.

X_1 = Area of floor space within zone classified as retail.

X_2 = Area of floor space within zone classified as service-office.

All floor space values are in units of thousands of square feet.

O-D Zone	Computed Total Person Trips	Observed Total Person Trips
01	8,580	18,380
02	3,542	3,840
03	5,250	3,010
04	14,388	40,130
05	10,724	11,730
06	20,480	14,870
07	8,767	3,070
08	21,424	23,730
09	5,712	4,940

F Ratio = 31.88 Standard Error, $S(Y_t)$ = 5367

Correlation Coefficient, r = 0.9269 r^2 = 0.859

Statistical Data for Regression Coefficients

	Retail b_1	Service-Office b_2
Level of Significance	N.S.	5%
Partial Correlation Coefficient	0.467	0.761
Standard Error	5.330	1.691

Table 26. Total Person Destinations Related to Retail, Service-Office Floor Space Use -- Seattle, Washington

REGRESSION EQUATION: $Y_t = 13.656X_1 + 4.353X_2 - 129$,

where Y_t = Computed response, 24-hour person trips to CBD zone.

X_1 = Area of floor space within zone classified as retail.

X_2 = Area of floor space within zone classified as service-office.

All floor space values are in units of thousands of square feet.

O-D Zone	Computed Total Person Trips	Observed Total Person Trips
012	6,979	5,800
013	19,865	22,760
014	21,119	19,850
015	4,505	4,160
016	22,808	21,110
017	15,180	16,160
002	4,043	3,420
003	11,603	11,750
004	10,155	9,170
005	6,026	6,920
006	1,695	2,960
007	7,621	8,950
008	2,744	1,340

F Ratio = 294.39

Standard Error, $S(Y_t) = 1512$

Correlation Coefficient, $r = 0.982$

$r^2 = 0.964$

Statistical Data for Regression Coefficients

	Retail b_1	Service-Office b_2
Level of Significance	0.1%	0.1%
Partial Correlation Coefficient	0.981	0.900
Standard Error	0.857	0.668

Table 27. Total Person Destinations Related to Retail, Service-Office Floor Space Use -- Baltimore, Maryland

REGRESSION EQUATION: $Y_t = 12.814X_1 + 4.518X_2 - 75$,

where Y_t = Computed response, 24-hour person trips to CBD zone.

X_1 = Area of floor space within zone classified as retail.

X_2 = Area of floor space within zone classified as service-office.

All floor space values are in units of thousands of square feet.

O-D Zone	Computed Total Person Trips	Observed Total Person Trips
010	7,640	9,780
011	22,926	19,410
012	14,822	20,300
020	20,770	21,230
021	7,143	9,910
022	10,288	15,300
023	3,226	3,670
030	20,727	27,830
031	22,135	18,110
040	10,196	7,570
041	8,248	2,620
051	11,063	3,460

F Ratio = 32.28 Standard Error, $S(Y_t)$ = 5198

Correlation Coefficient, r = 0.8215 r^2 = 0.675

Statistical Data for Regression Coefficients

	Retail b_1	Service-Office b_2
Level of Significance	1%	N.S.
Partial Correlation Coefficient	0.795	0.489
Standard Error	3.260	2.680

Table 28. Total Person Destinations Related to Retail, Service-Office Floor Space Use -- Pittsburgh, Pennsylvania

REGRESSION EQUATION: $Y_t - 12.43X_1 + 5.50X_2 - 264,$

where Y_t = Computed response, 24-hour person destinations to CBD zone.

X_1 = Area of floor space within zone used for retail sales.

X_2 = Area of floor space within zone used for service-office purposes.

All floor space values are expressed in thousands of square feet.

O-D Block*	Computed Total Person Destinations	Observed Total Person Destinations
33-64	6,642	7,300
42-48	1,437	1,289
43-69	8,169	9,285
48-63	8,707	6,275
57-54	3,318	1,829
64-49	3,974	2,288
71-64	11,605	9,723
73-45	15,171	19,508
75-75	1,944	1,457
59-73	622	1,423

F Ratio = 161.52 Standard Error, S (Y_t) = 1,336

Correlation Coefficient, r = 0.9102 r^2 = 0.828

Statistical Data for Regression Coefficients

	Retail b_1	Service-Office b_2
Level of Significance	0.1%	0.1%
Partial Correlation Coefficient	0.891	0.733
Standard Error	0.844	0.681

*Model was developed from data from 59 blocks, 10 of which are shown.

Table 29. Total Person Destinations Related to Retail, Service-Office Floor Space Use -- Detroit, Michigan

REGRESSION EQUATION: $Y_t = 13.505X_1 + 4.776X_2 - 380$,

where Y_t = Computed response, 24-hour person trips to CBD zone.

X_1 = Area of floor space within zone classified as retail.

X_2 = Area of floor space within zone classified as service-office.

All floor space values are in units of thousands of square feet.

O-D Zone	Computed Total Person Trips	Observed Total Person Trips
00	85,542	85,850
01	100,399	99,670
11	84,009	25,260
12	12,697	8,210
13	5,145	2,760
15	11,625	11,800
17	18,173	19,030
19	7,350	10,000

F Ratio = 656.49 Standard Error, $S(Y_t)$ = 3071

Correlation Coefficient, r = 0.9976 r^2 = 0.995

Statistical Data for Regression Coefficients

	Retail b_1	Service-Office b_2
Level of Significance	0.1%	0.1%
Partial Correlation Coefficient	0.994	0.991
Standard Error	0.663	0.282

Table 30. Total Person Destinations Related to Retail, Service-Office Floor Space Use -- Philadelphia, Pennsylvania

REGRESSION EQUATION: $Y_t = 15.079X_1 + 5.930X_2 - 2584,$

where Y_t = Computed response, 24-hour person trips to CBD zone.

X_1 = Area of floor space within zone classified as retail.

X_2 = Area of floor space within zone classified as service-office.

All floor space values are in units of thousands of square feet.

O-D Zone*	Computed Total Person Trips	Observed Total Person Trips
0001; 0002	90,623	88,490
0003	10,665	28,860
0005; 0006	103,640	103,690
0007; 0008	2,394	77,200
0043	0	3,700
0042	0	1,790
0063	3,036	2,540
0061	2,389	8,340
0045	11,434	4,550
0047	7,226	3,850

F Ratio = 302.65 Standard Error, $S(Y_t)$ = 557

Correlation Coefficient, r = 0.9787 r^2 = 0.958

Statistical Data for Regression Coefficients

	Retail b_1	Service-Office b_2
Level of Significance	0.1%	0.1%
Partial Correlation Coefficient	0.910	0.891
Standard Error	0.129	0.057

*Only 10 selected zones of a total of 31 are shown.

APPENDIX D

WORK TRIP MODELS

Table 31. Work Trips Related to Service, Office, Public Floor Space Use -- Gainesville, Georgia

REGRESSION EQUATION: $Y_w = 6.33X_r + 2.61X_o + 19.88X_p + 67$,

where Y_w = Computed response, 24-hour person destinations to CBD zone for work.

X_r = Area of floor space within zone used for services.

X_o = Area of floor space within zone used for offices.

X_p = Area of floor space within zone used for public purposes.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Work Destinations	Observed Work Destinations
01-006	524	600
01-010	564	598
01-003	723	739
01-001	912	832
01-011	322	538
01-004	168	68
05-009	180	47
01-002	190	150
01-007	86	146
01-009	136	146
01-005	86	131
01-008	362	192

F Ratio = 42.97 Standard Error, $S(Y_w)$ = 115

Correlation Coefficient, r = 0.9403 r^2 = 0.884

Statistical Data for Regression Coefficients

	Service b_r	Office b_o	Public b_p
Level of Significance	1%	5%	0.1%
Partial Correlation Coefficient	0.791	0.677	0.890
Standard Error	1.734	1.004	3.601

Table 32. Work Trips Related to Service, Office Floor Space Use -- Charlotte, North Carolina

REGRESSION EQUATION: $Y_w = 8.17X_o - 7.87X_r + 2439$,

where Y_w = Computed response, 24-hour person destinations to CBD zone for work.

X_o = Area of floor space within zone used for offices.

X_r = Area of floor space within zone used for services.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Work Destinations	Observed Work Destinations
6111	8,057	7,908
6112	1,213	1,172
6113	3,397	3,100
6114	5,932	6,146
6115	3,615	3,883

F Ratio = 365.91 Standard Error, $S(Y_w)$ = 339

Correlation Coefficient, r = 0.9958 r^2 = 0.994

Statistical Data for Regression Coefficients

	Office b_o	Service b_r
Level of Significance	1%	N.S.
Partial Correlation Coefficient	0.996	- 0.944
Standard Error	1.949	0.543

Table 33. Work Trips Related to Retail, Service Floor Space Use -- Chattanooga, Tennessee

REGRESSION EQUATION: $V_w = 0.72X_s + 5.93X_r + 158,$

where V_w = Computed response, 24-hour vehicle destinations to CBD zone for work.

X_s = Area of floor space within zone used for retail sales.

X_r = Area of floor space within zone used for personal and business services.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Vehicle Work Destinations	Observed Vehicle Work Destinations
511	6,397	6,444
512	158	344
513	1,522	1,410
514	360	328
515	2,494	2,549
516	2,089	1,956

F Ratio = 799.59 Standard Error, $S(V_w)$ = 150

Correlation Coefficient, r = 0.9987 r^2 = 0.997

Statistical Data for Regression Coefficients

	Sales b_s	Service b_r
Level of Significance	N.S.	0.1%
Partial Correlation Coefficient	0.869	0.994
Standard Error	0.238	0.368

Table 34. Work Trips Related to Retail, Public Floor Space Use -- Pittsburgh, Pennsylvania

REGRESSION EQUATION: $Y_w = 8.29X_s + 14.44X_p + 290$,

where Y_w = Computed response, 24-hour person destinations to CBD zone for work.

X_s = Area of floor space within zone used for retail sales.

X_p = Area of floor space within zone used for public purposes.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Work Destinations	Observed Work Destinations
60-80	6,503	4,710
80-80	6,724	7,384
40-60	14,664	14,500
60-60	11,765	10,385
80-60	10,841	11,925
40-40	2,676	3,673
60-40	8,743	7,699
80-40	19,552	20,568
60-20	1,160	1,792
80-20	4,919	4,911

F Ratio = 238.58 Standard Error, $S(Y_w)$ = 1,211

Correlation Coefficient, r = 0.9824 r^2 = 0.965

Statistical Data for Regression Coefficients

	Retail b_s	Public b_p
Level of Significance	0.1%	0.1%
Partial Correlation Coefficient	0.974	0.918
Standard Error	0.730	2.362

APPENDIX E

SHOPPING TRIP MODELS

Table 35. Shopping Trips Related to Sales, Office, Public Floor Space Use -- Gainesville, Georgia

REGRESSION EQUATION: $Y_s = 3.05X_s + 4.52X_o + 17.67X_p - 80$,

where Y_s = Computed response, 24-hour person destinations to CBD zone for shopping.

X_s = Area of floor space within zone used for retail sales.

X_o = Area of floor space within zone used for offices.

X_p = Area of floor space within zone used for public purposes.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Shopping Destinations	Observed Shopping Destinations
01-006	382	368
01-010	512	426
01-003	989	976
01-001	1,288	1,407
01-011	192	58
01-004	66	52
05-009	0	3
01-002	21	26
01-007	0	199
01-009	32	17
01-005	0	40
01-008	158	17

F Ratio = 60.19 Standard Error, $S(Y_s)$ = 115

Correlation Coefficient, r = 0.9759 r^2 = 0.951

Statistical Data for Regression Coefficients

	Sales b_s	Office b_o	Public b_p
Level of Significance	1%	1%	1%
Partial Correlation Coefficient	0.864	0.846	0.812
Standard Error	0.784	2.028	4.496

Table 36. Shopping Trips Related to Sales, Office Floor Space Use -- Gainesville, Georgia

REGRESSION EQUATION: $Y_s = 4.53X_s + 5.57X_o - 71$,

where Y_s = Computed response, 24-hour person destinations to CBD zone for shopping.

X_s = Area of floor space within zone used for retail sales.

X_o = Area of floor space within zone used for offices.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Shopping Destinations	Observed Shopping Destinations
01-006	312	368
01-010	803	426
01-003	1,037	876
01-001	1,068	1,407
01-011	19	58
01-004	116	52
05-009	0	3
01-002	62	26
01-007	26	199
01-009	94	17
01-005	0	40
01-008	60	17

F Ratio = 28.83 Standard Error, $S(Y_s)$ = 186

Correlation Coefficient, r = 0.9275 r^2 = 0.860

Statistical Data for Regression Coefficients

	Sales b_s	Office b_o
Level of Significance	0.1%	1%
Partial Correlation Coefficient	0.882	0.764
Standard Error	0.806	1.568

Table 37. Shopping Trips Related to Retail Floor Space Use* -- Gainesville, Georgia

REGRESSION EQUATION: $Y_s = -0.030X_s^2 + 13.78X_s - 148$,

where Y_s = Computed response, 24-hour person destinations to CBD zone for shopping.

X_s = Area of floor space within zone used for retail sales, expressed in thousands of square feet.

O-D Zone	Computed Shopping Destinations	Observed Shopping Destinations
01-006	230	368
01-003	819	976
01-001	1,427	1,407
01-011	112	58
01-004	0	52
05-009	59	3
01-002	5	26
01-007	118	199
01-009	293	17
01-005	0	40
01-008	216	17

F Ratio = 40.07 Standard Error, $S(Y_s)$ = 156

Correlation Coefficient, r = 0.9549 r^2 = 0.912

Statistical Data for Regression Coefficients

	$b(X_s^2)$	$b(X_s)$
Level of Significance	N.S.	1%
Partial Correlation Coefficient	0.548	0.800
Standard Error	0.0051	3.653

*Zone 01-010 was omitted.

Table 38. Shopping Trips Related to Retail Floor Space Use* -- Gainesville, Georgia

REGRESSION EQUATION: $Y_s = 503.3Ln(X_s) - 1299$,

where Y_s = Computed response, 24-hour person destinations to CBD zone for shopping.

X_s = Area of floor space within zone used for retail sales, expressed in thousands of square feet. The independent variable is the natural logarithm of X_s.

O-D Zone	Computed Shopping Destinations	Observed Shopping Destinations
01-006	402	368
01-003	946	976
01-001	1,406	1,407
05-009	84	3
01-002	0	26
01-007	215	199

F Ratio = 329.76

Standard Error, $S(Y_s)$ = 68

Correlation Coefficient, r = 0.9942

r^2 = 0.988

Statistical Data for Regression Coefficients

	$Ln(X_s)$
Level of Significance	0.1%
Partial Correlation Coefficient	0.994
Standard Error	27.146

*Model was developed for six selected zones. Zones 01-011, 01-004, 01-009, 01-010, 01-005, and 01-008 were omitted.

Table 39. Shopping Trips Related to Retail, Office Floor Space Use -- Charlotte, North Carolina

REGRESSION EQUATION: $Y_s = 6.68X_s - 8.45X_o + 3075$,

where Y_s = Computed response, 24-hour person destinations to CBD zone for shopping.

X_s = Area of floor space within zone used for retail sales.

X_o = Area of floor space within zone used for offices.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Shopping Destinations	Observed Shopping Destinations
6111	4,577	4,434
6112	3,798	4,701
6113	2,196	981
6114	133	806
6115	897	678

F Ratio = 9.720 Standard Error, $S(Y_s)$ = 1,188

Correlation Coefficient, r = 0.9131 r^2 = 0.834

Statistical Data for Regression Coefficients

	Retail b_s	Office b_o
Level of Significance	N.S.	N.S.
Partial Correlation Coefficient	0.908	- 0.844
Standard Error	0.691	1.199

Table 40. Shopping Trips Related to Retail, Personal, and Business Service, Floor Space Use -- Chattanooga, Tennessee

REGRESSION EQUATION: $V_s = 2.27X_s + 0.53X_r - 154,$

where V_s = Computed response, 24-hour vehicle destinations to CBD zone for shopping.

X_s = Area of floor space within zone used for retail sales.

X_r = Area of floor space within zone used for personal and business services.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Vehicle Shopping Destinations	Observed Vehicle Shopping Destinations
511	3,247	3,355
512	0	48
513	1,142	901
514	0	21
515	281	159
516	100	58

F Ratio = 88.03 Standard Error, $S(V_s)$ = 213

Correlation Coefficient, r = 0.9921 r^2 = 0.984

Statistical Data for Regression Coefficients

	Sales b_s	P & B Service b_r
Level of Significance	1%	N.S.
Partial Correlation Coefficient	0.968	0.505
Standard Error	0.338	0.523

Table 41. Shopping Trips Related to Retail Floor Space Use -- Chattanooga, Tennessee

REGRESSION EQUATION: $V_s = 0.00123X_s^2 + 0.992X_s + 26,$

where V_s = Computed response, 24-hour vehicle destinations to CBD zone for shopping.

X_s = Area of floor space within zone used for retail sales, expressed in thousands of square feet.

O-D Zone	Computed Vehicle Shopping Destinations	Observed Vehicle Shopping Destinations
511	3,356	3,355
512	26	48
513	902	901
514	55	21
515	140	159
516	64	58

F Ratio = 6033.55 Standard Error, $S(V_s)$ = 26

Correlation Coefficient, r = 0.9999 r^2 = 0.999

Statistical Data for Regression Coefficients

	$b(X_s^2)$	$b(X_s)$
Level of Significance	0.1%	1%
Partial Correlation Coefficient	0.994	0.986
Standard Error	0.0000075	0.098

Table 42. Shopping Trips Related to Retail Floor Space Use -- Pittsburgh, Pennsylvania

REGRESSION EQUATION: $Y_s = 0.0112X_s^2 - 1.37X_s + 110$,

where Y_s = Computed response, 24-hour person destinations to CBD zone for shopping.

X_s = Area of floor space within zone used for retail sales, expressed in thousands of square feet.

O-D Block*	Computed Shopping Destinations	Observed Shopping Destinations
33-64	74	27
42-48	69	114
43-69	3,753	5,700
48-63	3,148	1,783
57-54	612	775
64-49	371	817
71-64	7,579	6,111
73-45	12,282	12,933
75-75	106	552
59-73	99	5

F Ratio = 298.40 Standard Error, $S(Y_s)$ = 511

Correlation Coefficient, r = 0.9793 r^2 = 0.959

Statistical Data for Regression Coefficients

	$b(X_s^2)$	$b(X_s)$
Level of Significance	0.1%	N.S.
Partial Correlation Coefficient	0.855	- 0.199
Standard Error	0.0012	1.159

*Model was developed from data from 37 blocks, 10 of which are shown.

APPENDIX F

PERSONAL BUSINESS TRIP MODELS

Table 43. Business Trips Related to Service, Office, Public Floor Space Use -- Gainesville, Georgia

REGRESSION EQUATION: $Y_b = 3.60X_r + 5.62X_o + 15.03X_p + 29,$

where Y_b = Computed response, 24-hour person destinations to CBD zone for business.

X_r = Area of floor space within zone used for services.

X_o = Area of floor space within zone used for offices.

X_p = Area of floor space within zone used for public purposes.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Business Trips	Observed Business Trips
01-006	511	904
01-010	342	278
01-003	982	900
01-001	760	684
01-011	220	233
01-004	206	66
05-009	94	56
01-002	160	93
01-007	44	135
01-009	76	74
01-005	70	76
01-008	182	142

F Ratio = 20.21 Standard Error, $S(Y_b)$ = 160

Correlation Coefficient, r = 0.9089 r^2 = 0.826

Statistical Data for Regression Coefficients

	Service b_r	Office b_o	Public b_p
Level of Significance	N.S.	1%	5%
Partial Correlation Coefficient	0.465	0.816	0.725
Standard Error	0.768	0.444	1.595

Table 44. Business Trips Related to Retail, Office Floor Space Use -- Charlotte, North Carolina

REGRESSION EQUATION: $Y_b = 4.28X_o - 0.518X_s + 268$,

where Y_b = Computed response, 24-hour person destinations to CBD zone for business.

X_o = Area of floor space within zone used for offices.

X_s = Area of floor space within zone used for retail sales.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Business Destinations	Observed Business Destinations
6111	3,343	3,309
6112	551	873
6113	977	387
6114	2,240	2,299
6115	1,430	1,798

F Ratio = 25.73 Standard Error, $S(Y_b)$ = 508

Correlation Coefficient, r = 0.9508 r^2 = 0.903

Statistical Data for Regression Coefficients

	Office b_o	Retail b_s
Level of Significance	N.S.	N.S.
Partial Correlation Coefficient	- 0.365	0.881
Standard Error	0.934	1.624

Table 45. Business Trips Related to Retail, Personal and Business Service, Floor Space Use -- Chattanooga, Tennessee

REGRESSION EQUATION: $V_b = 0.37X_s + 1.42X_r + 83,$

where V_b = Computed response, 24-hour vehicle destinations to CBD zone for business purposes.

X_s = Area of floor space within zone used for retail sales.

X_r = Area of floor space within zone used for personal and business service.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Vehicle Business Trips	Observed Vehicle Business Trips
511	1,834	1,853
512	84	53
513	516	461
514	136	249
515	662	716
516	554	456

F Ratio = 152.12

Standard Error, $S(V_b) = 98$

Correlation Coefficient, $r = 0.9929$

$r^2 = 0.986$

Statistical Data for Regression Coefficients

	Sales b_s	Service b_r
Level of Significance	N.S.	1%
Partial Correlation Coefficient	0.810	0.959
Standard Error	0.155	0.242

Table 46. Business Trips Related to Retail, Public Floor Space Use -- Pittsburgh, Pennsylvania

REGRESSION EQUATION: $Y_b = 1.85X_s + 4.56X_p - 295,$

where Y_b = Computed response, 24-hour person destinations to CBD zone for business.

X_s = Area of floor space within zone used for retail sales.

X_p = Area of floor space within zone used for public purposes.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Business Destinations	Observed Business Destinations
60-80	1,491	1,481
80-80	1,421	1,413
40-60	3,215	3,337
60-60	2,351	1,771
80-60	2,129	2,369
40-40	377	755
60-40	1,932	1,860
80-40	4,814	5,051
60-20	0	179
80-20	1,148	603

F Ratio = 127.36 Standard Error, $S(Y_b)$ = 373

Correlation Coefficient, r = 0.9735 r^2 = 0.948

Statistical Data for Regression Coefficients

	Retail b_s	Public b_p
Level of Significance	0.1%	0.1%
Partial Correlation Coefficient	0.952	0.921
Standard Error	0.224	0.727

APPENDIX G

SOCIAL AND RECREATION TRIP MODELS

Table 47. Social-Recreation Trips Related to Sales, Service, Semi-Public Floor Space Use -- Gainesville, Georgia

REGRESSION EQUATION: $Y_{cr} = 1.56X_s - 1.55X_r + 3.65X_q + 109,$

where Y_{cr} = Computed response, 24-hour person destinations to CBD zone for social and recreation purposes.

X_s = Area of floor space within zone used for retail sales.

X_r = Area of floor space within zone used for services.

X_q = Area of floor space within zone used for semi-public purposes.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Social-Recreation Destinations	Observed Social-Recreation Destinations
01-006	118	512
01-010	359	190
01-003	365	445
01-001	426	461
01-011	136	84
01-004	224	140
05-009	105	42
01-002	106	70
01-007	136	50
01-009	74	88
01-005	116	188
01-008	157	50

F Ratio = 5.38 Standard Error, $S(Y_{cr})$ = 1644

Correlation Coefficient, r = 0.612 r^2 = 0.375

Statistical Data for Regression Coefficients

	Sales b_s	Service b_r	Semi-Public b_q
Level of Significance	N.S.	N.S.	N.S.
Partial Correlation Coefficient	0.536	- 0.174	0.324
Standard Error	0.868	3.106	3.772

Table 48. Social-Recreation Trips Related to Retail, Service Floor Space Use -- Charlotte, North Carolina

REGRESSION EQUATION: $Y_{cr} = 1.276X_s - 1.217X_r + 754$

where Y_{cr} = Computed response, 24-hour person destinations to CBD zone for social and recreation purposes.

X_s = Area of floor space within zone used for retail sales.

X_r = Area of floor space within zone used for services.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Destinations	Observed Destinations
6111	2,221	2,232
6112	735	645
6113	797	689
6114	901	942
6115	629	776

F Ratio = 112.76 Standard Error, $S(Y_{cr}) = 147$

Correlation Coefficient, r = 0.9877 $r^2 = 0.976$

Statistical Data for Regression Coefficients

	Retail b_s	Services b_r
Level of Significance	5.0%	N.S.
Partial Correlation Coefficient	0.987	- 0.686
Standard Error	0.147	0.913

Table 49. Social Trips Related to Personal and Business Service, Amusement, Hotel Floor Space Use -- Chattanooga, Tennessee

REGRESSION EQUATION: $V_c = 1.55X_r - 11.26X_a - 0.84X_h + 25$,

where V_c = Computed response, 24-hour vehicle destinations to CBD zone for social purposes.

X_r = Area of floor space within zone used for services.

X_a = Area of floor space within zone used for amusement purposes.

X_h = Area of floor space within zone classified as hotels.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Vehicle Social Destinations	Observed Vehicle Social Destinations
511	228	233
512	13	58
513	66	42
514	36	10
515	187	286
516	146	138

F Ratio = 22.41

Standard Error, $S(V_c)$ = 42

Correlation Coefficient, r = 0.9714

r^2 = 0.944

Statistical Data for Regression Coefficients

	Service b_r	Amusement b_a	Hotel b_h
Level of Significance	5%	N.S.	N.S.
Partial Correlation Coefficient	0.960	- 0.920	- 0.802
Standard Error	0.160	0.169	0.221

Table 50. Recreation Trips Related to Personal and Business Service, Amusement, Hotel Floor Space Use -- Chattanooga, Tennessee

REGRESSION EQUATION: $V_r = 2.25X_r - 1.95X_a - 1.90X_h - 38$,

where V_r = Computed response, 24-hour vehicle destinations to CBD zone for recreation purposes.

X_r = Area of floor space within zone used for services.

X_a = Area of floor space within zone used for amusement purposes.

X_h = Area of floor space within zone classified as hotels.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Vehicle Recreation Destinations	Observed Vehicle Recreation Destinations
511	1,153	1,166
512	0	16
513	308	249
514	32	32
515	730	742
516	163	143

F Ratio = 141.71 Standard Error, $S(V_r)$ = 59

Correlation Coefficient, r = 0.9967 r^2 = 0.993

Statistical Data for Regression Coefficients

	Service b_r	Amusement b_a	Hotel b_h
Level of Significance	5%	N.S.	5%
Partial Correlation Coefficient	0.990	- 0.499	- 0.974
Standard Error	0.227	2.394	0.403

Table 51. Social-Recreation Trips Related to Retail, Service Floor Space Use -- Pittsburgh, Pennsylvania

REGRESSION EQUATION: $Y_{cr} = 0.868X_s - 0.509X_r + 806,$

where Y_{cr} = Computed response, 24-hour person destinations to CBD zone for social and recreation purposes.

X_s = Area of floor space within zone used for retail sales.

X_r = Area of floor space within zone used for services.

All floor space values are expressed in thousands of square feet.

O-D Zone	Computed Destinations	Observed Destinations
60-80	631	1,758
80-80	443	947
40-60	868	387
60-60	1,141	1,590
80-60	1,123	1,416
40-40	640	232
60-40	683	496
80-40	871	448
60-20	750	0
80-20	303	182

F Ratio = 4.82 Standard Error, $S(Y_{cr})$ = 655

Correlation Coefficient, r = 0.4207 r^2 = 0.177

Statistical Data for Regression Coefficients

	Retail b_s	Services b_r
Level of Significance	N.S.	N.S.
Partial Correlation Coefficient	0.396	- 0.272
Standard Error	0.761	0.682

APPENDIX H

A BRIEF DESCRIPTION OF CURRENT TECHNIQUES FOR ESTIMATING FUTURE CBD FLOOR SPACE REQUIREMENTS

In this Appendix, an attempt is made to briefly describe certain of the techniques currently employed by city planners to estimate future floor space requirements for the central business district. The material presented herein has been largely abstracted from theses by Shirley F. Weiss[24] and Andrew Karl Toth.[25]

A variety of approaches have been used or proposed by city planners to estimate future CBD floor space use, but these approaches may be thought of as belonging to one of five basic groups: (1) population; (2) purchasing power; (3) business establishments: (4) employment; and (5) daytime population. It is not uncommon for floor space projections to be based on a combination of these to arrive at the over-all future space needs for the CBD.

By far the most popular indicator of floor space requirements is population increase. Projections based on future population estimates have been related to city population, urban area population, and trading area population. Most forecasts which use this approach begin with current floor space requirements, basing estimates of future needs on a projected ratio between population and square feet of floor space or directly on expected population in the metropolitan or trading area. The Denver Planning Office, for example, estimated total future space need in the CBD by simply multiplying the projected metropolitan population by 32.5 square feet of CBD space per person. The Least Squares method has been used in relating population and CBD floor space needs;[24] however, most city planners seem to prefer a more subjective approach to the problem.

The purchasing power method has been used to estimate retail sales space requirements for the CBD. By this method, retail floor space needs are based on an analysis of family income and expenditures for the trade area population.

> The first step requires a delimiting of the trade area followed by estimates of: families or households, household income used for the purchase of retail merchandise and service, that portion of the total expenditure spent on retail merchandise, that portion of retail expenditure to be spent at the center and which can be supported by expected volume of business.[25]

This method, while sound in principle, is "cumbersome and baffling in application."[25] In addition, the number and type of assumptions that must be made for the purchasing power method casts doubt on its reliability.

A third method of estimating future CBD floor space requirements is the "business establishments" approach. Using this approach, the first step involves classifying the various establishments in the CBD accouding to function. Forecasts of the number of establishments are made by regression equations based on national, regional, and local trends. Similar forecasts for average floor space requirements are made using past trends for the CBD under study. Total floor space projections are then obtained by multiplying the estimated number of establishments in each subgroup by the corresponding projected average floor space required. The overall space requirements for the CBD is then based on the summation of the projections of the subgroups. Reliability of this method is dependent upon the detail in which the analysis is made. Its usefulness is restricted to larger metropolitan areas "where the number of establishments and their variety of functional space requirements justify the use of average space per establishment."[24]

Employment forecasts have been useful in estimating future floor space requirements for certail work functions in the CBD. This method has been used most extensively for estimating public and private office requirement, although future retail space needs have also been estimated by this technique. By this method, floor space forecasts are usually made by simply multiplying the estimated number of workers by an average space per employee, such as 150 square feet of floor space per office employee. Application of this method depends upon the availability of suitable tabulations of CBD employment data. Futhermore, the standard average space per employee probably does not remain constant with time and should be adjusted on a subjective basis to allow for changes wrought by improved working conditions, automation, etc.

Basing future floor space requirements on changes in daytime population is a fifth method which has been proposed but not yet tested. Basic data for this approach would be obtained from origin-destination surveys. In view of the many imponderables involved in estimating future daytime population of the CBD, this technique would seem to be of questionable merit.

In an understatement, Weiss[24] observes that "methods of estimating current daytime population in the CBD are farther advanced than those for forecasting future daytime population."

Noting the conditions of variability attendant to forecasts of daytime population, Toth[25] concludes that "this method is rejected for forecasting future space requirements, but provides an excellent approach for testing location theory and forecasting open space, thoroughfare, and parking requirements."

Floor space forecasts are usually based on several of the above approaches, the particular technique employed depending upon the functional type of floor space under study. Indeed, several independent estimates may be made for each category of floor space use. These techniques are often altered or modified to allow for existing or anticipated trends.

In a Tacoma study,[26] the retail space forecast was based on population and buying power. Office space estimates were also based on population but consideration was given to competition with Seattle and other Puget Sound cities for office employment.

A Salisbury, North Carolina, study,[27] estimated that commercial and industrial space requirements would increase 1.5 times the rate of the trade area population, reflecting the increasing amount of expendable income within the trade area. In this study, it was concluded that industrial space was not directly related to population, and future industrial space requirements were made by projecting past trends in industrial front footage.

In Dallas, three estimates of office building construction were made: one based on population; one based on office employment; and another based on past trends of office space use.[28] Using these methods, it was estimated that office space use increase by 1980 would be, respectively: 6,608,625; 7,040,000; and 10,816,722 square feet.

In the Dallas study, the estimate of retail floor space took into consideration a large number of determinants. It was estimated that increased office employment in the CBD would generate a need for 100,000 square feet of new retail space. A like amount of new space would be required by additions to the inventory of shops and stores in the central district. Growing convention activity in the city would induce an increase for at least 25,000 square feet of retail space. Another 100,000 square feet of retail space would be required because of increased business activity resulting from growth in office facilities in the central area. The study estimated that 200,000 square feet of space would be required to provide retail services to persons who would reside in central district apartments. Finally, it was estimated that special retail stores (tobacco shops, lunch stands, etc.) on the ground floor of new office buildings would occupy approximately 200,000 square feet of retail space. Based on these various influences, it was estimated that the total increase in CBD retail floor space use by 1980 would be 725,000 square feet.

It is believed that reasonably precise estimates of future CBD floor space use can be made by thoughtful application of the techniques that have been described. Furthermore, having decided upon the desirable future nature and size of the central business district, there are certain steps which a city can take to bring about fulfillment of its planners' prophecy for the city center. There is little doubt that city planners, by intelligent and persistent application of the zoning ordinance, building code, and capital improvement program, working together with economic and political leaders, can significantly influence the future character of the CBD. To this extent, then, future CBD floor space projections may take on the nature of self-fulfilling predictions.

Respectfully submitted:

Donald O. Covault
Project Director

Paul H. Wright
Assistant Professor

LIST OF REFERENCES

1. Committee for Economic Development, Guiding Metropolitan Growth, New York August, 1960.

2. Harper, B. C. S., and Edwards, H. M., A Study of the Generation of Person Trips by Areas in the Central Business District, Ontario Joint Highway Research Programme, Queen's University, Kingston, Ontario, May, 1960.

3. Huhtanen, Robert J., Mika, Paul J., Preston, Richard E., and Murphy, Raymond E., A Study of the Effects of Freeways on Central Business Districts, Clark University, February, 1961.

4. Horwood, Edgar M., and Boyce, Ronald R., Studies of the Central Business District and Urban Freeway Development, University of Washington Press, Seattle, 1959.

5. U. S. Department of Commerce, Bureau of Public Roads, Parking Guide for Cities, Washington, D. C., 1956.

6. Burrage, Robert H., and Mogren, Edward G., Parking, The Eno Foundation for Highway Traffic Control, Saugatuck, Connecticut, 1957.

7. Murphy, Raymond E., and Vance, Jr., J. E., "Delimiting the CBD," Economic Geography, Vol. 30, 1954.

8. Gorman, David A., and Hitchcock, Stedman T., "Characteristics of Traffic Entering and Leaving the Central Business District," Public Roads, Vol. 30 No. 9, August, 1959.

9. McMillan, Samuel C., "Recent Trends in the Decentralization of Retail Trade," Traffic Quarterly, Saugatuck, Connecticut, January, 1962.

10. Future Highways and Urban Growth, prepared for Automobile Manufacturers Association by Wilbur Smith and Associates, February, 1961

11. Vernon, Raymond, The Changing Economic Function of the Central City, Committee for Economic Development, New York, 1959.

12. Smith, Wilbur S., "The Changing Function of the CBD and Its Influence on Urban Transportation Needs," presented at the Environmental Engineering Conference, American Society of Civil Engineers, Atlanta, February, 1962.

13. Mitchell, Robert B., Metropolitan Planning for Land Use and Transportation, Office of Public Works Planning, The White House, December, 1959.

14. Kennison, David L., The Gravity Model, Masters Thesis, Georgia Institute of Technology, March, 1963.

15. Fratar, T. J., "Vehicular Trip Distribution by Successive Approximations," Traffic Quarterly, Saugatuck, Connecticut, January, 1954.

16. Osofsky, Sam, "The Multiple Regression Method of Forecasting Traffic Volumes," Traffic Quarterly, Saugatuck, Connecticut, July, 1959.

17. Voorhees, Alan M., "A General Theory of Traffic Movement," Proceedings of the Institute of Traffic Engineers, 1955.

18. Smith, Wilbur S., "Analyzing and Projecting Travel Data," Journal of the Highway Division, A.S.C.E., June, 1960.

19. Mills, W. Raymond, "Future Trip Length," Traffic Quarterly, Saugatuck, Connecticut, April, 1963.

20. Ezekiel, Mordecai, and Fox, Karl A., Methods of Correlation and Regression Analysis, 3rd Edition, John Wiley and Sons, Inc., New York, 1959.

21. Brownlee, K. S., Industrial Experimentation, Chemical Publishing Company, New York, 1953.

22. U. S. Census of Business: 1954, Volume II, Bureau of the Census, Washington, 1956.

23. Shopping Habits and Travel Patterns, Special Report 11-B, Highway Research Board, Washington, D. C., 1955.

24. Weiss, Shirley F., The Central Business District in Transition: Methodological Approaches to CBD Analysis and Forecasting Future Space Requirements, Masters Thesis, University of North Carolina, Chapel Hill, 1958.

25. Toth, Anthony K., Central Area Planning, Masters Thesis, Cornell University, Ithaca, 1959.

26. The Central Core, Tacoma Central Business District Studies: Part I, City Planning Commission, Tacoma, Washington, June, 1959.

27. Preliminary Central Business District Plan, 1980, Salisbury, North Carolina, Department of Conservation and Development, Raleigh, 1960.

28. Dallas Central District, Department of City Planning, Dallas, Texas, February, 1961.

OTHER REFERENCES

Barnes, Charles F., "Projection of Travel Patterns in the Greater Hartford Area," Traffic Quarterly, The Eno Foundation, January, 1962.

Bendtsen, P. H., Town and Traffic in the Motor Age, Danish Technical Press, Copenhagen, 1961.

Blackburn, Jack B., "The Civil Engineer and Urban Transportation," Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, September, 1961.

Connell, Arnall T., Land Uses that Require a Central Business District Location, Masters Thesis, Georgia Institute of Technology, 1955.

Curran, Frank, B., and Stegmaier, Joseph T., "Travel Patterns in 50 Cities," Public Roads, December, 1958.

Dearinger, John A., "Auto Trips to the Central Business District," Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, September, 1962.

Fisher, Sir Ronald A., Statistical Methods for Research Workers, 13th Edition, Hafner Publishing Company, New York, 1958.

Fortune, Editors of, The Exploding Metropolis, Doubleday and Company, New York, 1958.

Gulick, Luther, "Observations on Urban Transportation," Journal of the City Planning Division, Proceedings of the American Socity of Civil Engineers, September, 1961.

Harper, B. C. S., and Edwards, H. M., "Generation of Person Trips by Areas within the Central Business District," Highway Research Board Bulletin, No. 253, 1960.

Highway Research Board, Forecasting Highway Trips, Bulletin No. 297, 1961.

Highway Research Board, Urban Transportation Planning, Bulletin No. 293, 1961.

Journal of the American Institute of Planners, "Land Use and Traffic Models," Special Issue, May, 1959.

Journal of the American Institute of Planners, "Planning the City's Center," Special Issue, February, 1961.

Lapin, Howard S., "The Analysis of Work Trip Data: Relationships and Variances," Traffic Quarterly, Saugatuck, Connecticut, 1957.

Mertz, William L., and Hamner, Lamelle B., "A Study of Factors Related to Urban Travel," Public Roads, April, 1957.

Qualls, William H., The Problems and Delimitation of the Central Business District, Masters Thesis, Georgia Institute of Technology, 1954.

Reynolds, Robert B., Retail Specialization of Central Business Districts, Masters Thesis, Georgia Institute of Technology, 1954.

Schmidt, Robert E., and Campbell, E. Earl, Highway Traffic Estimation, The Eno Foundation, Sangatuck, Connecticut, 1957.

Shuldiner, Paul W., "Trip Generation and the Home," Highway Research Board Bulletin No. 347, 1962.

Silver, Jacob, "Relationships between Land Use and Economic Activity and Travel," mimeographed paper used for a class in "Traffic Assignment and Forecasting Utilizing Electronic Computer Techniques," Washington, D. C., October, 1962.

Silver, Jacob, "Trends in Travel to the Central Business District by Residents of the Washington, D. C., Metropolitan Area, 1948 and 1955," Public Roads, April, 1959.

Smith, Wilbur S., "Urban Transportation Tasks of the Future," Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, May, 1962.

Taylor, Gerald K., A Study of the Relationships of Land Value and Land Use in the Central Business District, Masters Thesis, Georgia Institute of Technology, 1956.

Thabit, Walter, and Lobe, Nathalie, "Shopper Origins and Destinations," Traffic Quarterly, Saugatuck, Connecticut, April, 1957.

Wood, Robert C., Metropolis Against Itself, Committee for Economic Development, New York, March, 1959.

VITA

Paul Hamblen Wright was born in Mt. Juliet, Tennessee, on March 12, 1932, son of John E. and Maxie Hamblen Wright. He received his early education in the public schools of Wilson County, Tennessee. He attended David Lipscomb College and was graduated from the University of Tennessee in 1953 with a Bachelor of Science in Civil Engineering.

Beginning in January, 1954, the writer served three and one-half years as an officer in the U. S. Navy Civil Engineer Corps. Upon his release from Naval service, he returned to the University of Tennessee for graduate study in Civil Engineering. He graduated in December, 1958, with a Master of Science degree.

Mr. Wright has held positions with Beiswenger Hoch and Associates, Consulting Engineers, and the Davidson County Highway Department, both of Nashville, Tennessee.

In 1961, the writer was awarded a Ford Foundation Fellowship to study towards a Ph.D. degree at the Georgia Institute of Technology. From September, 1961, until September, 1963, he held the position of Graduate Assistant at Georgia Tech.

Since September, 1963, Mr. Wright has served as Assistant Professor, School of Civil Engineering, Georgia Institute of Technology.

He is married to the former Joyce Sparkman of Sparta, Tennessee, and is the father of a five year old son, Paul Jeffrey.