

Relationships of Traffic and Floor Space Use in Central Business District

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In 1960, Harper and Edwards developed linear regression models for seven cities relating traffic flow to the central business district to floor space use. This is an extension in which models are developed for cities over a wide population range and for trips made for different purposes. Significant models were developed for total traffic and for work, shopping, and business trips. Social and recreation trips to the CBD were not found to be significantly related to floor space use. The research showed that traffic flow to the CBD is most closely related to the following classifications of floor space use: retail sales, service, office, and public. No significant relationships were found between traffic and manufacturing, wholesaling, and semi-public floor space use.

By using common floor space groupings of retail and service-office, it is shown that regression coefficients for these variables are significantly related to city population. However, important differences in the models were noted for cities of similar size, suggesting that more research is needed to identify and quantify other sources of variation in the regression coefficients.

It is also shown that regression coefficients in linear models relating CBD traffic flow and floor space use are influenced by the size and number of origin-destination zones. The use of smaller zones tends to produce better stratification of the data and results in more reliable models.

•THE PAST century has witnessed dramatic shifts in the growing population of the United States. In 1850, only 15 percent of the population lived in urban areas. By the turn of the century, this percentage had risen to 40 percent, 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.

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. Although 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.

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 con-

gestion and delays. The need for reliable predictions of traffic flow to the CBD 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 attracted to a city's CBD 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 of Harper and Edwards (1, 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.

METHOD OF STUDY

Using the Harper-Edwards study as a starting point, CBD floor space inventories and origin-destination (O-D) traffic studies were obtained for the cities of Pittsburgh, Pa.; Atlanta, Ga.; Chattanooga, Tenn.; Charlotte, N.C.; and Gainesville, Ga. 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 were assembled and tabulated by 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 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.

NOMENCLATURE

- Y_t = average 24-hour person destinations to CBD zone.
- 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.
- Y_m = average 24-hour person destinations to CBD zone for miscellaneous 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_1 = area of floor space within zone used for retail sales, Harper-Edwards model.
- X_2 = area of floor space within zone used for service-office purposes, Harper-Edwards model.
- X_3 = area of floor space within zone used for manufacturing-warehousing purposes, Harper-Edwards model.

RESULTS

In this study, more than 100 regression equations were developed relating traffic flow to the CBD to floor space use within the CBD. Statistical data for 42 of these models were given in a recent thesis (3). Twelve typical models are described in the succeeding paragraphs.

Total Traffic Models

The research indicated that total trips to the CBD are most closely related to retail sales, office, and public floor space use. Typical models for total 24-hour person destinations to CBD zones are as follows:

$$\text{Gainesville: } Y_t = 8.98 X_s + 21.12 X_o + 63.26 X_p + 216 \quad (1)$$

$$\text{Atlanta: } Y_t = 9.58 X_s + 7.52 X_o - 1137 \quad (2)$$

$$\text{Pittsburgh: } Y_t = 12.14 X_s + 6.25 X_r - 76 \quad (3)$$

Statistical data for these equations, as well as a zone-by-zone comparison of computed and observed traffic, are given in Tables 1, 2, and 3. In each of these total traffic models, the coefficient of multiple correlation exceeded 0.90, and all three models were significant at the 0.1 percent level.

In the Gainesville equation, traffic was most closely correlated with office floor space use, whereas retail sales floor space was the most significant variable in the Atlanta and Pittsburgh models.

TABLE 1
TOTAL DESTINATIONS RELATED TO
SALES, OFFICE, PUBLIC FLOOR SPACE
USE—GAINESVILLE, GA.^a

O-D Zone	Total Person Destinations	
	Computed	Observed
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

^aRegression equation = Eq. 1; F ratio = 90.82; standard error, $S(Y_t) = 398$; correlation coefficient, $R = 0.9778$; $r^2 = 0.956$; statistical data for regression coefficients:

Factor	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

Of particular interest in Eq. 1 is the remarkably high regression coefficient for public floor space use which 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.

Effect of City Population on
Total Traffic Models

To provide a basis for comparing the results of their analysis of different cities, Harper and Edwards (2) related person destination to the CBD to three common floor space groups: retail (X_1), service-office (X_2), and manufacturing-warehousing (X_3). Typical floor space classifications included in these groups are given in Table 4. The model proposed by Harper and Edwards was of the form:

$$Y_t = b_1 X_1 + b_2 X_2 + b_3 X_3 + K \quad (4)$$

TABLE 2

TOTAL PERSON DESTINATIONS RELATED TO RETAIL, OFFICE FLOOR SPACE USE—ATLANTA, GA.^a

O-D Zone	Total Person Destinations	
	Computed	Observed
144	3,642	4,378
146	6,412	5,582
148	9,885	9,168
150	4,391	4,614
152	7,437	3,911
155	2,005	2,639
156	9,118	9,433
157	5,981	5,911
158	1,463	2,903
161	16,255	18,046

^aRegression equation = Eq. 2; F ratio = 71.80, standard error, $S(Y_t) = 1,691$; correlation coefficient, $R = 0.9466$; $r^2 = 0.896$; statistical data for regression coefficients:

Factor	Retail, b_s	Office, b_o
Level of significance (%)	0.1	5
Partial correlation coefficient	0.946	0.782
Standard error	1.245	2.265

TABLE 3

TOTAL PERSON DESTINATIONS RELATED TO RETAIL, SERVICE FLOOR SPACE USE—PITTSBURGH, PA.^a

O-D Block ^b	Total Person Destinations	
	Computed	Observed
33-64	7,345	7,300
42-48	1,197	1,280
43-69	7,629	9,285
48-63	8,951	6,275
57-54	3,435	1,829
64-49	4,058	2,288
71-64	11,450	9,723
73-45	15,127	19,508
75-75	1,994	1,457
59-73	645	1,423

^aRegression equation = Eq. 3; F ratio = 153.89; standard error, $S(Y_t) = 1,365$; correlation coefficient, $R = 0.9060$; $r^2 = 0.821$; statistical data for regression coefficients:

Factor	Retail, b_s	Office, b_r
Level of significance (%)	0.1	0.1
Partial correlation coefficient	0.883	0.719
Standard error	0.862	0.807

^bModel developed from data from 59 blocks, 10 of which are shown.

Models of this type were developed for Gainesville, Charlotte, and Chattanooga, providing a measure of the influence of city size on the total traffic model. These models, along with those developed by Harper and Edwards are given in Table 5.

TABLE 4

TYPICAL FLOOR SPACE CLASSIFICATIONS INCLUDED IN GROUPS USED BY HARPER AND EDWARDS

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 5

MODELS FOR TEN CITIES RELATING TOTAL PERSON DESTINATIONS
TO CBD TO RETAIL, SERVICE-OFFICE, AND MANUFACTURING-
WAREHOUSING FLOOR SPACE USE

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

A study of the models in Table 5 revealed that the manufacturing-warehousing floor space variable is not closely related to traffic destinations. Of the ten manufacturing-warehousing coefficients shown, only two are significant, even at the 20 percent 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 given in Table 6.

The omission of the manufacturing-warehousing variable did not appear to have a harmful effect on 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 given in Table 7.

Utilizing the regression coefficients in the three-dimensional models given in Table 6, relationships were developed between population and the retail and service-office coefficients:

$$b_1 = 0.00150 (\text{population, thousands}) + 9.72 \quad (5)$$

$$b_2 = 22.61 - 2.33 \ln (\text{population, thousands}) \quad (6)$$

Plots of these functions are shown in Figures 1 and 2.

TABLE 6

MODELS FOR TEN CITIES RELATING TOTAL PERSON
DESTINATIONS TO CBD TO RETAIL AND SERVICE-
OFFICE FLOOR SPACE USE

City	Population	Model
Gainesville	16,787	$Y_t = 10.96 X_1 + 16.48 X_2 + 171$
Charlotte	202,000	$Y_t = 9.89 X_1 + 15.68 X_2 + 1404$
Chattanooga	283,170	$Y_t = 8.89 X_1 + 7.31 X_2 - 1388$
Tacoma	275,876	$Y_t = 6.20 X_1 + 7.22 X_2 - 1049$
Vancouver	600,000	$Y_t = 15.38 X_1 + 9.76 X_2 + 3898$
Dallas	614,799	$Y_t = 6.89 X_1 + 4.86 X_2 + 1475$
Seattle	732,922	$Y_t = 13.66 X_1 + 4.35 X_2 - 129$
Baltimore	1,337,373	$Y_t = 12.81 X_1 + 4.52 X_2 - 75$
Detroit	3,016,197	$Y_t = 13.50 X_1 + 4.78 X_2 - 380$
Philadelphia	3,671,048	$Y_t = 15.08 X_1 + 5.93 X_2 - 2584$

TABLE 7
STANDARD ERRORS AND CORRELATION COEFFICIENTS OF
HARPER-EDWARDS MODELS VS MODELS WITHOUT
MANUFACTURING-WAREHOUSING COEFFICIENT

City	Standard Error		Correlation Coefficient	
	With X_3	Without X_3	With X_3	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

Correlation coefficients for Eqs. 5 and 6 were, respectively, 0.57 and 0.79. Both models were significant at the 0.1 percent level.

The regression coefficient of 0.00150 in Eq. 5 is significant at the 10 percent level, whereas the regression coefficient of 2.33 in Eq. 6 is significant at the 1 percent level. Thus, it can be asserted with confidence that the service-office coefficients given in Table 6 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.

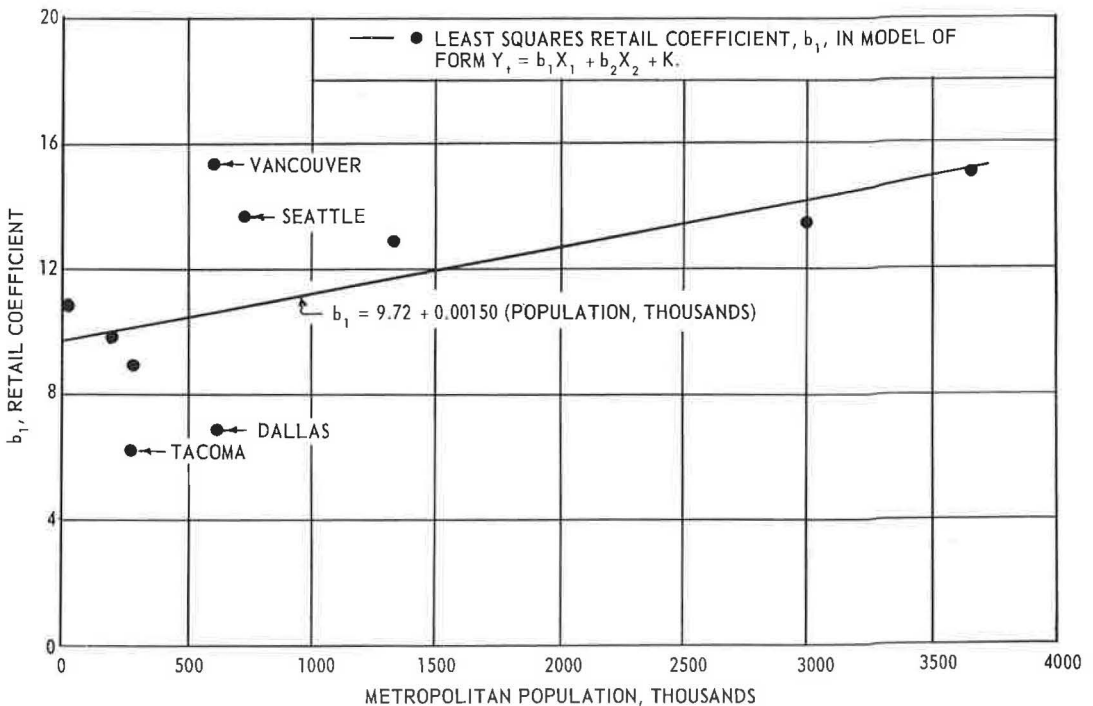


Figure 1. Relationship of retail coefficients to city population.

size. A comparison of certain economic measures of city vitality seems to mirror the differences noted in the traffic models. For example, it is probably more than coincidence that Charlotte, which had a higher retail coefficient, also exhibited higher per capita sales and a larger number of retail establishments per capita (4). It is also interesting to note that Charlotte, whose service-office coefficient was roughly twice that of Chattanooga, exceeds Chattanooga in employment in finance, insurance and real estate by approximately the same ratio (4).

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 6, 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 30 miles away. There is also reason to believe that the low regression coefficients in the Dallas model may be partially explained by the competition of the Fort Worth CBD 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 6 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, Atlanta, and Pittsburgh, and the results indicated that work trips are most closely related to public, service, sales, and office floor space use.

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 as follows:

$$Y_w = 6.33 X_r + 2.61 X_o + 19.88 X_p + 67 \quad (8)$$

With an F ratio of 42.97, this model was significant at the 0.1 percent 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 9.

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

For Atlanta, a very satisfactory model was computed which relates work trips to the CBD to floor space use for retail sales and offices:

$$Y_w = 3.44 X_s + 5.39 X_o + 105 \quad (9)$$

Correlation coefficient for Eq. 9 was 0.937, and its standard error was 700 person destinations. With an F ratio of 126.66, the model is significant at the 0.1 percent level. A zone-by-zone comparison of observed work trips and those computed by Eq. 9 is given in Table 10.

TABLE 9

WORK TRIPS RELATED TO SERVICE, OFFICE, PUBLIC FLOOR SPACE USE—GAINESVILLE, GA.^a

O-D Zone	Work Destinations	
	Computed	Observed
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

^aRegression equation = Eq. 8; F ratio = 42.97; standard error, $S(Y_w) = 115$; correlation coefficient, $R = 0.9403$; $r^2 = 0.884$; statistical data for regression coefficients:

Factor	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

Work trips to Pittsburgh's CBD evidenced a close relationship to retail and public floor space use. A multiple regression model relating these variables is as follows:

$$Y_w = 8.29 X_s + 14.44 X_p + 290 \quad (10)$$

This equation was characterized by very satisfactory correlation statistics, as were the regression coefficients. The model was significant at the 0.1 percent level. The coefficient of multiple determination indicated that more than 96 percent of the variation in traffic is explained by the model. For the seven most heavily traveled zones, computed traffic values vary less than 15 percent from the observed values. These data are given in Table 11.

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 this study shopping trips were found to be linearly related to sales, office, and public floor space use. However, the most satisfactory models were nonlinear equations relating shopping trips and retail floor space use.

Gainesville. —Eq. 11 is a least squares fit of the data for six of Gainesville's 12 zones and is weighted in favor of the most heavily traveled zones:

$$Y_s = 503.3 \ln (X_s) - 1299 \quad (11)$$

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

TABLE 10

WORK TRIPS RELATED TO RETAIL,
OFFICE FLOOR SPACE USE—
ATLANTA, GA.^a

O-D Zone	Work Destinations	
	Computed	Observed
144	3,452	3,369
146	4,224	4,178
148	4,711	4,170
150	2,889	3,032
152	3,903	2,472
155	2,028	2,254
156	6,840	6,976
157	3,822	4,046
158	1,852	2,485
161	6,478	7,217

^aRegression equation = Eq. 9; F ratio = 126.66; standard error, $S(Y_w) = 700$; correlation coefficient, $R = 0.9373$; $r^2 = 0.879$; statistical data for regression coefficients:

Factor	Retail, b_s	Office, b_o
Level of significance (%)	0.1	0.1
Partial correlation coefficient	0.930	0.908
Standard error	0.516	0.939

TABLE 11

WORK TRIPS RELATED TO RETAIL,
PUBLIC FLOOR SPACE USE—
PITTSBURGH, PA.^a

O-D Zone	Work Destinations	
	Computed	Observed
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

^aRegression equation = Eq. 10; 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:

Factor	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

Eq. 11 closely resemble the observed trips as evidenced by the small standard error.

A plot of Eq. 11 may be seen as Figure 4. Statistical data for this equation are given in Table 12.

In Figure 4, 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 support 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 "re-tail" stores evidently attract few shopping trips, but depend on CBD employees and shoppers that are attracted to the larger stores.

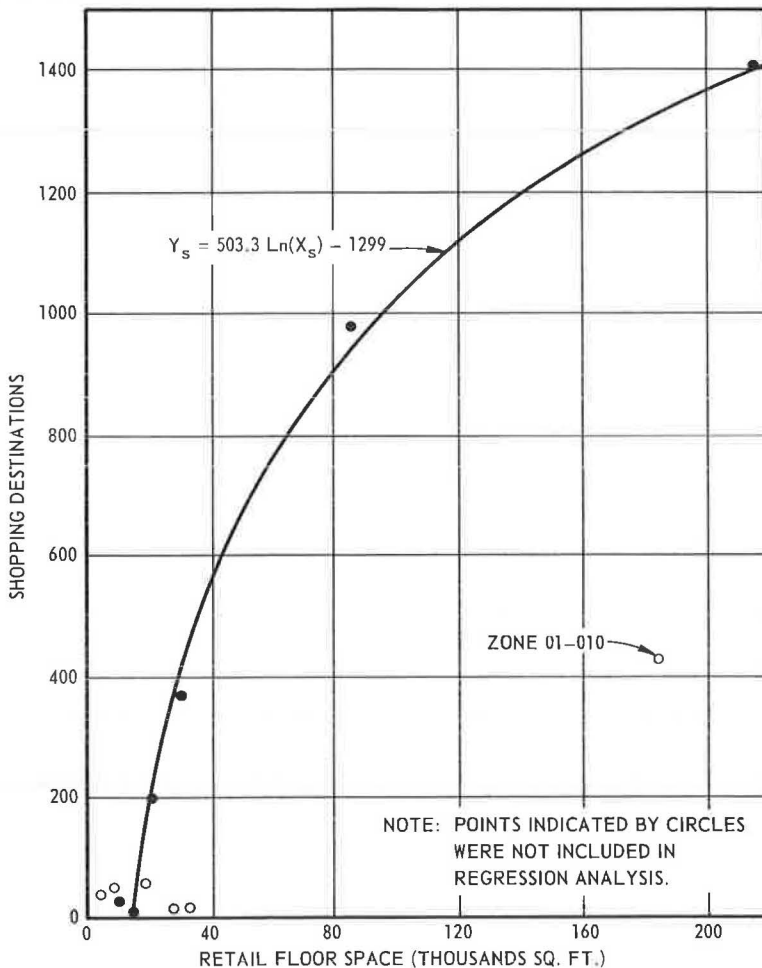


Figure 4. Relationship of shopping trips to Gainesville CBD to retail floor space use.

TABLE 12
SHOPPING TRIPS RELATED TO RETAIL
FLOOR SPACE USE—
GAINESVILLE, GA.^a

O-D Zone	Shopping Destinations	
	Computed	Observed
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

^aModel developed for six selected zones—zones 01-011, 01-004, 01-009, 01-010, 01-005, and 01-008 omitted; regression equation = Eq. 11; F ratio = 329.76; standard error, $S(Y_S) = 68$; correlation coefficient, $R = 0.9942$; $r^2 = 0.988$; regression coefficient $\ln(X_S)$: level of significance 0.1 percent, partial correlation coefficient 0.994, standard error 27.146.

and 161, where retail sales activity was highest, excellent agreement between the observed shopping trips and those computed with the model was noted (Table 13). A graph of Eq. 12, along with observed data, is shown in Figure 5.

Pittsburgh.—Eq. 13, a quadratic model relating shopping trips to the Pittsburgh CBD and retail floor space use, was highly significant:

$$Y_S = 0.00362X_S^2 - 1.71X_S + 274 \quad (12)$$

With an F ratio of 197.70, Eq. 12 was highly significant. The correlation coefficient for the model was 0.993 and its standard error was 369. For zones 148

TABLE 13
SHOPPING TRIPS RELATED TO RETAIL
FLOOR SPACE USE—
ATLANTA, GA.^a

O-D Zone	Shopping Destinations	
	Computed	Observed
144	237	109
146	145	209
148	1,983	2,241
150	114	185
152	805	52
155	143	106
156	84	367
157	175	594
158	220	35
161	8,709	8,715

^aRegression equation = Eq. 12; F ratio = 197.70; standard error, $X(Y_S) = 369$; correlation coefficient, $R = 0.9927$; $r^2 = 0.985$; statistical data for regression coefficients:

Factor	b (X_S^2)	b (X_S)
Level of significance (%)	0.1	N.S.
Partial correlation coefficient	0.956	-0.650
Standard error	0.00042	0.756

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 subclassifications 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.

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

$$Y_S = 0.0112X_S^2 - 1.37X_S + 110 \quad (13)$$

Statistical data for this model are given in Table 14. A plot of Eq. 13 and the observed data are shown in Figure 6.

With a high correlation coefficient and a small standard error, Eq. 13 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.

Personal Business Trip Models

The Gainesville and Pittsburgh data suggest that personal business trips are most closely related to sales, public, and office floor space use. In the Atlanta study, personal business trips were not given as a separate trip purpose but were included as "miscellaneous" trips.

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:

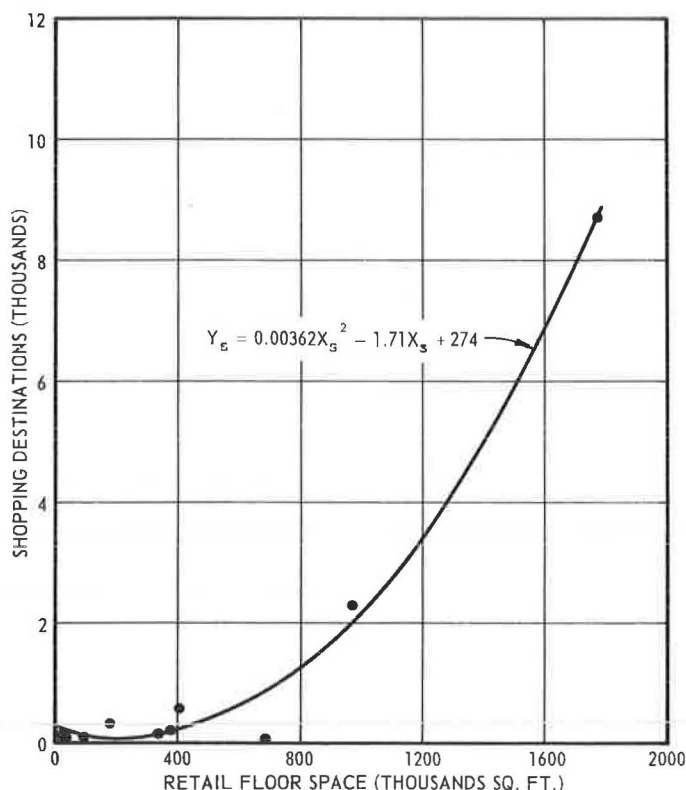


Figure 5. Relationship of shopping trips to Atlanta CBD to retail floor space use.

$$Y_b = 3.60 X_r + 5.62 X_o + 15.03 X_p + 29 \quad (14)$$

Statistically, this model was less satisfactory than the work and shopping trip models for Gainesville. The model was significant at the 0.1 percent level, but barely so. The correlation coefficient was only 0.9089, implying that only about 82 percent 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.

According to Eq. 14, 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, whole-sale, and semi-public floor space use.

Personal business trips to central Atlanta were grouped with medical, dental, and eat-meal trips as "miscellaneous" trips. Miscellaneous trips to the Atlanta CBD were related to sales and office floor space use:

$$Y_m = 0.91 X_s + 0.88 X_o + 144 \quad (15)$$

Although Eq. 15 was significant at the 0.1 percent level, its correlation coefficient of 0.867 suggests that only about 75 percent of the variation in traffic is explained by the model. Partial correlation coefficients for the sales and office variables were, respectively, 0.867 and 0.679.

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

TABLE 14
SHOPPING TRIPS RELATED TO RETAIL
FLOOR SPACE USE—
PITTSBURGH, PA.^a

O-D Block ^a	Shopping Destinations	
	Computed	Observed
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

^aModel developed from data from 37 blocks, 10 of which are shown; regression equation = Eq. 13; F ratio = 298.40; standard error, $S(Y_S) = 511$; correlation coefficient, $R = 0.9793$; $r^2 = 0.959$; statistical data for regression coefficients:

Factor	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

$$Y_b = 1.85X_S + 4.56X_p - 295 \quad (16)$$

This equation exhibited very satisfactory correlation statistics. The model was significant at the 0.1 percent 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 10 percent or less for six of the ten O-D zones. Very good statistical data for the regression coefficients were also noted.

Statistical data for Eqs. 14, 15 and 16 are given in Tables 15, 16, and 17, respectively.

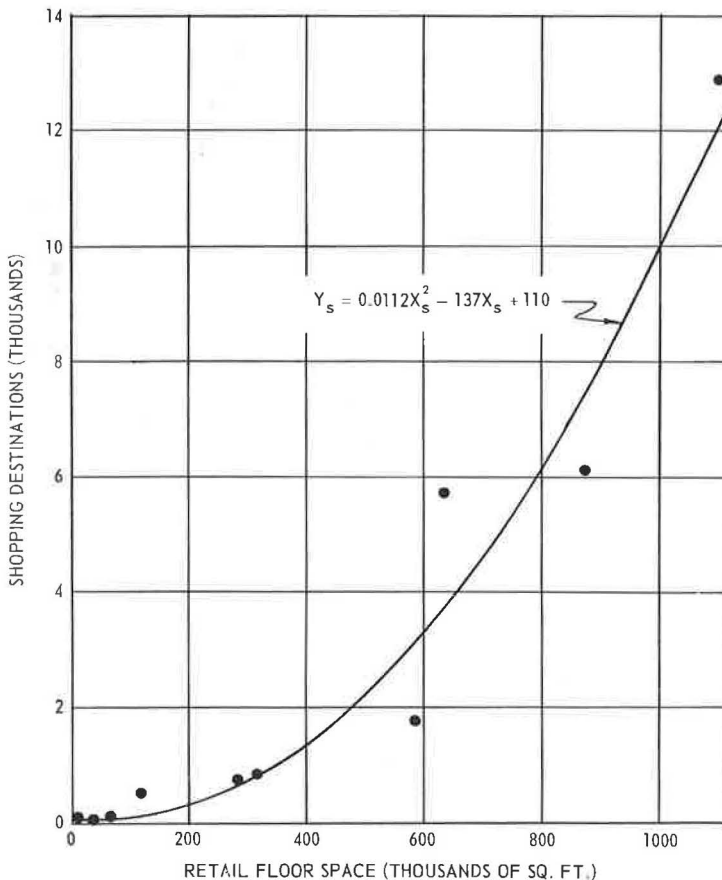


Figure 6. Relationship of shopping trips to Pittsburgh CBD to retail floor space use.

TABLE 15

BUSINESS TRIPS RELATED TO SERVICE,
OFFICE, PUBLIC FLOOR SPACE USE—
GAINESVILLE, GA.^a

O-D Zone	Business Trips	
	Computed	Observed
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

^aRegression equation = Eq. 14; 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 17

BUSINESS TRIPS RELATED TO RETAIL,
PUBLIC FLOOR SPACE USE—
PITTSBURGH, PA.^a

O-D Zone	Business Destinations	
	Computed	Observed
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

^aRegression equation = Eq. 16; F ratio = 127.36; standard error, $S(Y_b) = 373$; correlation coefficient, $r = 0.9735$; $r^2 = 0.948$; statistical data for regression coefficients:

Factor	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

TABLE 16

MISCELLANEOUS TRIPS RELATED TO
RETAIL, OFFICE FLOOR SPACE USE—
ATLANTA, GA.^a

O-D Zone	Miscellaneous Destinations	
	Computed	Observed
144	701	501
146	951	986
148	1,235	1,225
150	720	1,232
152	1,007	852
155	493	248
156	1,312	1,294
157	895	1,201
158	442	308
161	1,810	1,720

^aRegression equation = Eq. 15; F ratio = 49.23; standard error, $S(Y_m) = 269$; correlation coefficient, $R = 0.8674$; $r^2 = 0.752$; statistical data for regression coefficients:

Factor	Sales, b_s	Office, b_o
Level of significance (%)	1	5
Partial correlation coefficient	0.867	0.679
Standard error	0.198	0.361

Social and Recreation Trip Models

Predictive models for social and recreation trips were consistently poor, and the results of this study indicate 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.

CONCLUSIONS

1. The number of people attracted to a zone within a city's CBD 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 (Fig. 7).

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.

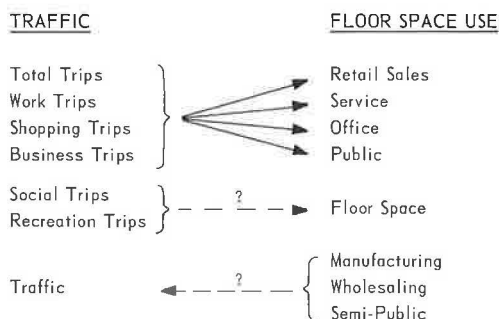


Figure 7. Relationships between traffic attracted to zones in a city's CBD to various classes of floor space use.

it is 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 frequently 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. 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 sizes are due to variations in intensity of floor space occupancy.

9. 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. Although 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.

10. 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.

11. 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 nonlinear.

12. 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.

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

4. Traffic attracted to the CBD 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 O-D zones. The selection of small homogeneous zones tends to produce better stratification and increased reliability of the data. In future O-D studies, therefore,

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