Generation of Person Trips by Areas Within the Central Business District

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City planners have for some time been saying that the traffic which flows in and out of a city each day is generated by the buildings in the center. So far as could be ascertained, such statements had not been checked, yet if some relationship did exist it would probably provide new ways of predicting future travel to the CBD by using floor-space forecasts. An investigation was undertaken to see if a relationship between floor space in use and travel to the CBD could be demonstrated, and secondly, if such a relationship existed in one city, to develop similar ones for other cities and endeavor by means of a comparison to estimate the form of a similar relationship in cities of different sizes and different predominant economic activities.

The method developed used the results of O-D studies and planning commissions' CBD floor-space surveys. Floor space in use in each O-D zone was classified into the three broad groups of retail, service (office and manufacturing), and warehousing. These figures were then considered as variables causing the difference in the number of persons shown by the O-D survey to have destination in the various CBD zones. A statistical regression technique was then used to determine a relationship between the variables.

The relationship between floor-space usage and the number of persons with destination in an O-D zone was found to be particularly well-developed. The mathematical relationship determined by the regression analysis was able to predict the person destinations with generally less than 20 percent error and in the zones of high attraction within the order of 2 percent. With this repeated in all of the seven cities studied, the truth of the relationship suspected by some city planners was demonstrated conclusively. It is believed that the extent of the error could be further reduced by considering a larger number of floor-space variables or by modifying the mathematical law slightly.

The investigation, which considered only metropolitan areas with populations of 250,000 persons or more, included the cities of Philadelphia, Pa., Detroit, Mich., Baltimore, Md., Seattle, Wash., Vancouver, B.C., Tacoma, Wash., and Dallas, Tex. A comparison of the equations for Philadelphia, Detroit, Baltimore and Seattle showed great similarities. Vancouver and Dallas, which were based on somewhat less complete floor-space information, also showed sufficient similarities to suggest that floor space in all these cities attracts people to the center at approximately the same rate. Tacoma, on the other hand, appears to represent another group, although the analysis in that city was seriously limited by the data available, and the result must be regarded as inconclusive.

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There is reason to believe that the investigation has shown that the number of people attracted to an area in a city's center is closely related to the floor area being used for various purposes in the section of the CBD considered. This relationship appears sufficiently well-developed to form a suitable basis for estimating future travel to the center. An equation of the type developed, used in conjunction with good economic forecasts of future floor-space use, should provide reasonably accurate forecasts of future travel to the center. The limited results show that there is a good deal of similarity among cities where the attraction of people to the CBD is considered. If more equations could be developed for cities in which O-D and floor-space studies have been made, it may be possible to formulate equations to suit other cities in which O-D studies have not been performed, which would be of great value in transportation planning. The similarities among the equations for Philadelphia, Detroit, Baltimore and Seattle are so great that it seems reasonable to suggest that if an equation is developed for a city in this population range, it will change very little as the city grows. In other words, although the central floor area may increase and the CBD grow in size, the trip attraction rate would not be expected to change appreciably.

● IT IS GENERALLY recognized that the success of highway planning in a city depends upon the ability of the planner to predict the future volumes of traffic for which the planned street system should prove adequate. The present prediction techniques, based on the projection of recent rates of increase, cannot be regarded as entirely satisfactory, and the development of some sounder methods appears to be warranted. Ideally, a prediction should take into account the changing habits and customs of people and possible technological changes affecting their mode of travel, as well as considering possible land-use changes affecting the travel patterns.

Some workers in the field of city planning have been saying that the traffic which flows in and out of a city each day is generated by the buildings, or rather the businesses that occupy and use the buildings in the center. So far as could be ascertained, such statements have not been checked, yet if some relationship did exist it could provide a new way of predicting future travel to the central business district. To investigate this, the Ontario Joint Highway Research Program sponsored research at Queen's University to see if a relationship between amount of floor area in use in various classifications and travel to the central business district (CBD) could be demonstrated. As a second part to the study it was hoped to estimate the form of similar relationships in cities of different sizes and with different predominant economic activities by means of a comparison of floor area attraction relationships from a number of cities.

All highway planning is concerned with the provision of facilities for the movement of people and goods at some future time. As such it seems that a prediction in terms of the volume and requirements of movements of people and goods rather than cars and trucks will form the most satisfactory base for planning. Such a prediction, if it takes into account foreseeable land-use changes as well as possible changes in peoples' habits and customs, will provide a picture of the required movements which will remain constant and relatively unaffected by technological change. A transportation system can then be designed to suit these volumes, utilizing the expected mode of travel and foreseeable technological change in the means of travel to decide on the characteristics of the individual branches in the network.

Based on the idea of obtaining a knowledge of future person movement, the relationship investigated was between floor space in use and the number of person destinations in the area rather than the number of automobiles attracted. To relate floor area to person destinations may appear a formidable task, requiring a large amount of detailed material giving the specific destinations and purposes which brought people to the center. However, it was believed that sufficient information was presently contained in the results of comprehensive home-interview origin-and-destination (O-D) traffic surveys and CBD floor-area studies to enable an investigation to be made based on these two surveys.

The floor-area studies give the floor area in use in the O-D survey zones, so that for each zone the floor area in use in a number of main classifications could be determined. If floor area is a measure of attraction of people to the center then there should be some relationship between these figures and the O-D survey totals for the number of people with destination in these zones in an average 24-hr period. The division of the CBD into zones in the traffic survey provides a series of floor-area versus person destination observations necessary for the statistical derivation of a regression equation. The coefficients found for the equations then provide estimates of the attraction effect of the different floor-area use types considered in the analysis.

For an investigation of this kind, in which an attempt was made to formulate a new approach to traffic prediction, it was thought justifiable to adopt an over-simplified approach to the problem. Complex relationships could probably be developed on the basis of fine differences in floor-area use classification. However, it was felt that the grouping of floor areas into three broad-use categories would prove simple but adequate. Although it may not be extremely accurate it could show whether the traffic pattern was related to floor area in use and also indicate the necessity of making any refinements in the floor-area classification.

The three broad categories chosen—retail, service-office and manufacturing-warehousing—have fairly distinct characteristics and tend, by their grouping, to give character to different parts of the city center. It was reasoned that different types of floor-area use, classified into any one of these groups, would most probably give rise to different rates of attraction. This could be a serious drawback to using such a small number of classifications. Nevertheless, the spread within a category may not be too large and if it is remembered that the success of any traffic prediction by this method will depend on the ability to forecast floor-area use, which cannot be done accurately in small groupings, it can be seen that the selection of broad grouping is justified. The use classifications listed by the various planning authorities are given in Appendix A grouped into the categories used in this study.

MATHEMATICAL MODEL

A multiple regression analysis enables the investigation and determination of a relationship from observed phenomena which may be exceedingly difficult to determine from theoretical considerations. However, its use is limited for it must depend on theoretical or intuitive understanding of the relationship in order to determine the form of the mathematical law to be investigated. A consideration of the conditions in the core of a CBD seemed to indicate that the correct form of a mathematical relationship between floor-area and person destinations would be linear. Therefore it was decided to see how well the observations fitted an equation of the form:

$$Y = b_1X_1 + b_2X_2 + b_3X_3 + k \qquad (1)$$

in which

- Y = number of person destinations in a zone in the CBD in an average 24-hr period from within the metropolitan area;
- X_1 = area of retail floor space in use in the zone expressed in thousands of sq ft;
- X_2 = area of service-office floor space in use in the zone expressed in thousands of sq ft;
- X_3 = area of manufacturing-warehousing floor space in use in the zone expressed in thousands of sq ft;
- b_1 = coefficient of retail floor space generation when considered in conjunction with service-office and manufacturing-warehousing space;
- b_3 = coefficient of service-office floor space generation when considered in conjunction with retail and manufacturing-warehousing space;

b_3 = coefficient of manufacturing-warehousing floor space generation when considered in conjunction with retail and service-office space; and

k = constant.

A linear law of this type implies that each additional square foot of space in use, within each type, in a zone, will cause an identical increase in the number of people attracted. Obviously there are certain parts of what might be classed as a CBD to which a law such as this would not be expected to apply at all. For example, if the area is slowly growing in a certain direction, a zone in the growing fringe may be lacking somewhat in attraction. With additional development such a zone can supply a greater diversity of goods and services and as a result becomes a more popular area. In such a case, the addition of extra floor space has a cumulative effect, and instead of each additional square foot in use attracting equal numbers of people, increasing numbers are attracted and the correct mathematical model would probably be curvilinear with a power law at least for the retail variable. Manufacturing-warehousing and service-office are unlikely to be greatly influenced by the cumulative effect and the equation variables most probably always have a power index of close to unity. However, when a zone becomes well-developed and has large amounts of different types of floor space in use, any cumulative effect will undoubtedly dissipate and the attraction law will probably be linear. Even with greatly increased development in a zone the linear relationship should continue to represent the conditions of attraction, for a law of diminishing returns would restrain any retail business from using more and more floor space if each additional square foot used attracted fewer and fewer people.

If this reasoning is correct, then the linear law will only apply to the core of a CBD and will probably not represent the conditions of attraction to a growing and dying fringe. Because of this, it is important to fix the core area. This was not possible in the investigation because the analysis was made using the area classed as CBD by the traffic and floor-space studies, and as a result it was expected that some of the fringe zones would not be well described by the selected relationship.

Because the larger cities were more likely to have made floor-space studies, the investigation was confined to cities classified by the 1950 U.S. Bureau of Census as having standard metropolitan areas with a resident population of 250,000 persons or more. Some of the existing O-D studies were not suitable for a regression analysis because the CBD was divided into only one or two zones, while in the case of other cities, floor-space surveys were not available. Nevertheless, sufficient information was available to undertake analyses of the cities given in Table 1.

An investigation of this table will show the difficulty of obtaining close time agreement between land use and travel information. It was believed that an analysis relating these two surveys would be valid in the case of Philadelphia, Detroit and Vancouver because of the small time difference involved, but the other cities presented a problem.

Inasmuch as it was believed that floor area in use was a reliable measure of the business activity which attracted people to the central area, it was necessary to estimate how well the later floor-space information represented the conditions at the time of the O-D study. This would be an extremely difficult, if not impossible, condition to demonstrate. Some change is always occurring in any city and this must have affected the use of floor space within the various zones of the O-D studies. However, a statistical regression technique actually balances out variations in the observations to determine the equation that best describes the information available. Because of this the redistribution of floor-space use that has occurred in the time between the two surveys may not be too critical as long as the general use has been relatively stable. The regression equations determined for cities with considerable time difference between surveys will probably not fit the data as well as those for the cities with negligible time difference, but the resulting equations will most probably provide a reasonable estimate of the attraction laws which would have been obtained had coincidental data been available.

It was possible to estimate the general state of floor-space use in Baltimore and Seattle using the work of Norwood and Boyce of the University of Washington (1). Their

TABLE 1

CITIES, POPULATION, AND DATES OF FIELD SURVEYS COMPARED IN REGRESSION ANALYSIS

Met. Area	State or Province	1950 Population in Standard Met. Area	O-D Field Survey Date	CBD Floor-Space Survey Date
Philadelphia	Pennsylvania	3,671,048	1947	1949
Detroit	Michigan	3,016,197	1953	1954
Baltimore	Maryland	1,337,373	1946	1957
Seattle	Washington	732,992	1946	1956
Vancouver	British Columbia	600,000	1955[1]	1954
Tacoma	Washington	275,876	1948	1958
Dallas	Texas	614,799	1951	[2]

[1] Vancouver's travel information comes from a survey of vehicle owners and public transit users, and as a result may not be as reliable as that provided by the home-interview survey.
[2] See notes for Table 10, Appendix B.

work, in which census returns and questionnaires were used to estimate CBD change, showed that retail sales had decreased with a corresponding decrease in retail workers. It was impossible to determine retail floor-space change from the census returns but the data did show that there had been no change in the over-all amount of office space in use in central Baltimore, and only a 15 percent decrease in the amount in use in Seattle during the 10-yr period, 1946-1954. These over-all pictures, although failing to produce definite proof, appear to indicate a fairly stable state of floor-space use and as a result the use of a regression analysis might be expected to provide reasonably valid results. Unfortunately no information was available for Tacoma and it was necessary to assume that a similar situation existed there.

The fitting of a regression equation to a set of observations is a statistical technique well described in a number of text books (2). In this analysis use was made of a set of statistics known as Gaussian multipliers to find the equation of "best fit." As a result of the analysis, the coefficients b_1, b_2, b_3 and the constant, k, in Eq. 1 were determined. These coefficients estimate the generative power of the three types of floor space used, in terms of the number of people attracted per 1,000 ft of floor space.

RESULTS OF THE ANALYSIS

The investigation set out to determine how useful a knowledge of floor space alone would be in estimating the attraction of people to the city center. The ability of the selected relationship to represent the actual conditions may be seen by examining Tables 4 to 10 (Appendix B). These tables show the O-D zone number, the floor area in use in each of the three classifications adopted, the number of person destinations in the zone as shown by the traffic survey and the number of person destinations estimated by the regression equation. It should be noted that estimated attraction corresponds to the observed surprisingly well. Although some zones show large errors, in nearly every city the zones which attract the greatest number of people are estimated with small percentage error, and generally the error in most zones is less than 20 percent. The closeness of the estimated and observed attraction of people to the zones, in the various cities indicates fairly conclusively that a knowledge of floor space in use provides a reasonable index of the attraction of the center. The magnitude of these errors could probably be reduced by considering a larger number of floor-space variables or by modifying the form of the mathematical law. In most cases the zones showing large errors are situated on the edge of the area classed as CBD by the traffic study, and are most likely outside the core area where the linear law could be expected to apply.

As would be expected, there is a greater range of error shown between estimated and observed attraction of zones in the cities with considerable time difference between surveys. Although the expected variations are apparent, the general trend in the floor-space attraction relationship is distinct and well-developed.

It should be mentioned that the development of a regression equation does not prove that variations in floor-space use actually cause the differences in attraction to a zone. However, the existence of these relationships and the fact that most people journeying to the center do so to transact some form of business with an occupier or user of floor space makes an inference of this kind highly probable. It seems therefore, that for highway planning it will be reasonable to use sound economic forecasts of future floor-space use in the central area as an index of the center's expected attraction, and, by means of an appropriate regression equation, estimates of the number of people who will be attracted in the future to areas within the CBD of the various cities can be made.

In discussing the form of mathematical model studied, the point was made that the linear law would probably only hold for the core area of the CBD. This was indicated in the analysis by the fact that the fringe zones generally showed a greater error of estimate than the central zones. Although the investigation of what may be classed as core would have been difficult, the use of the method depends on the fixing of some boundary within which equations of the type suggested may be used with confidence. The Murphy-Vance CBD outline (3) seemed to offer much promise as a frame within which the linear equation would probably apply.

The area available for analysis in Philadelphia was large and it was possible to compare the area delimited by the Murphy-Vance technique as the CBD with the area in which the linear law appeared to apply (Fig. 1). This analysis was complicated by the

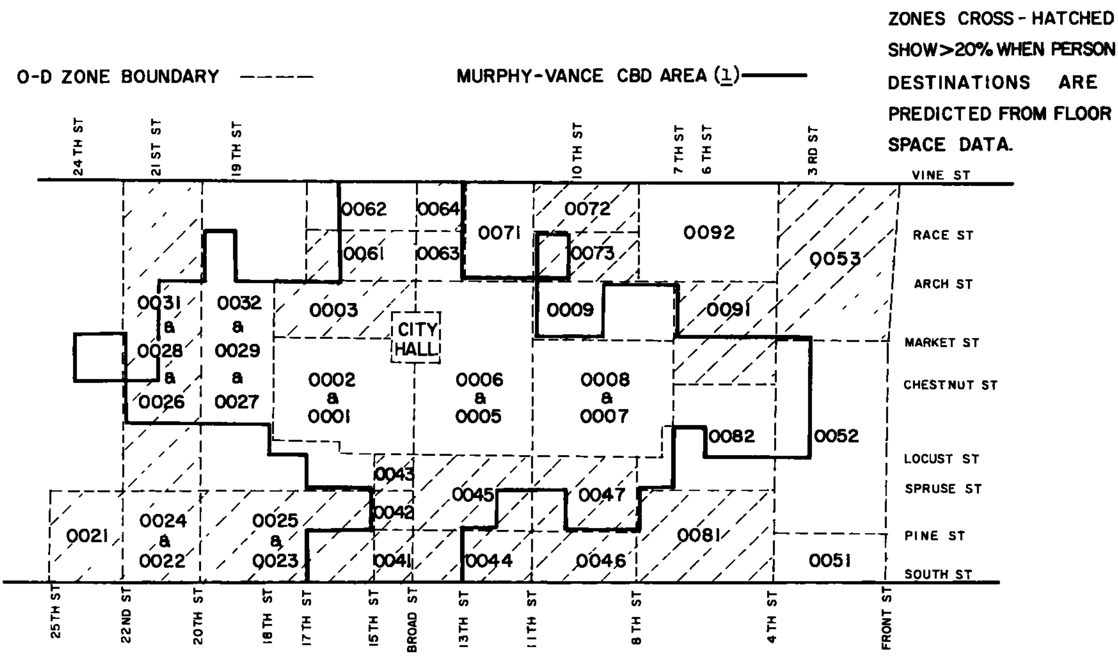

Figure 1. Philadelphia central area.

fact that in some cases the O-D study boundaries did not coincide with those used in the floor-space survey and zones had to be grouped with a resulting loss in sensitivity. Nevertheless, if the area in which person destinations could be estimated by means of the linear equation with less than 20 percent error is compared with the area delimited by the Murphy-Vance technique, reasonable agreement can be seen. If the use of a linear equation of the type suggested is restricted to the Murphy-Vance CBD area, the application appears to be valid.

COMPARISON OF CITIES

Any use of the equations developed would naturally depend on a continuation of the trip generative power of the three types of floor space at the determined value, or on reasonable estimates of the changes in the equation coefficients as the particular city grew. It was thought that similarities and differences in the attraction equations might be explainable on the basis of some characteristics of the city, such as size or predominant economic activity. Consequently, the attraction equations for the various cities were compared. The cities compared included a wide range of conditions (Table 2).

TABLE 2

LOCATION, POPULATION, AND SERVICE CLASSIFICATION OF CITIES COVERED IN ANALYSIS

Met. Area	State or Province	1950 Population in Standard Met. Area	Service[1] Classifications
Philadelphia	Pennsylvania	3, 671, 048	Finance Insurance Real estate
Detroit	Michigan	3, 016, 197	Manufacturing
Baltimore	Maryland	1, 337, 373	Diversified
Seattle	Washington	732, 992	Strongly financial Insurance Real estate
Vancouver	British Columbia	600, 000	-
Tacoma	Washington	275, 876	Public Administration and finance
Dallas	Texas	614, 799	Very strongly financial and wholesaling

[1] Nelson, J., "A Service Classification of American Cities." Economic Geography, XXXI No. 3, pp 189-210 (July 1955).

Table 3 sets out the various equations estimating trip attraction determined by the regression analysis. A study of this table immediately shows interesting similarities among the equations. This is particularly marked in the cases of Philadelphia, Detroit and Baltimore and to a lesser extent in the case of Seattle. The analyses of Vancouver, Tacoma and Dallas were limited by the data available as explained in the notes attached to Tables 8, 9 and 10, respectively (Appendix B). Still some similarities are apparent in all but the equation for Tacoma.

Statistical techniques such as the fitting of a regression line give results which are, in fact, estimates of an unknown set of "true" values. The equations determined cannot be regarded as the "true" equations which underly the observed differences but only estimates of these equations. The similarity of the equations for Philadelphia, Detroit and Baltimore could mean that, in actual fact, they are all estimates of the one "true" equation, and that the attraction of people to the zones in the central areas of all these cities is governed by the one law. While the X_3 coefficient in the equation for Seattle tends to made this city appear different from the first three mentioned, the extent

TABLE 3

EQUATIONS GOVERNING THE ATTRACTION OF PERSONS TO AREAS WITHIN THE CBD'S OF SEVEN CITIES ON THE BASIS OF FLOOR AREA IN USE

City	State or Province	Equation of Attraction
Philadelphia	Pennsylvania	$Y=14.602X_1 + 5.858X_2 + 1.276X_3 - 3,470$
Detroit	Michigan	$Y=13.918X_1 + 4.613X_2 + 1.717X_3 - 2,280$
Baltimore	Maryland	$Y=12.871X_1 + 4.524X_2 + 1.343X_3 - 1,080$
Seattle	Washington	$Y=13.678X_1 + 4.382X_2 + 0.152X_3 - 200$
Vancouver	British Columbia	$Y=14.322X_1 + 10.534X_2 + 3.670X_3 + 1,560$
Tacoma	Washington	$Y= 7.709X_1 + 2.493X_2 - 17.692X_3 + 3,590$
Dallas[1]	Texas	$Y=16.191X_1 + 3.546X_2 + 12.265X_3 - 8,570$

[1] The floor-space information in Dallas was estimated from a map and as a result cannot be classed as accurate. This equation is included to show the rough similarity between it and the first three.

of the difference is not sufficient to rule out the possibility that the attraction equation for Seattle may be the same as that governing trip patterns in Philadelphia, Detroit and Baltimore.

On the other hand, each of the unknowns in the equation could be influenced by some characteristic of the city or the city center. Although this was not thought to be the case, because of the great similarity of the equations, a comparison of the equation coefficients was made on the basis of various indices. The indices selected were population, retail floor space per head, retail floor space per $1,000 of retail sales, office space per head and per worker in selected service trades, manufacturing-warehousing space per head and per worker in production and wholesale activities. These comparisons failed to show any trend and seemed to give strength to the belief that the equations presented probably estimate one general equation applying to large cities irrespective of variations in size, location, or predominant economic activity.

One interesting fact emerging from this comparison was that Vancouver showed a significantly higher ratio of service workers per 1,000 sq ft of service-office floor space than any of the other cities. This ratio was, of course, influenced by differences in the material reported in the Canadian and American censuses, and by variations in the size of the area classed as the CBD. This fact could possibly account for the high service-office space generation coefficient shown in the equation for that city, but as explained in the notes attached to Table 8, the assumption made in converting acres of site area to floor area in the manufacturing-warehousing classification could seriously influence the Vancouver analysis.

No definite conclusions can be reached in the case of Tacoma, for the equation is based on only five observations and the estimate provided by the analysis may be greatly in error. However, the extent of the difference between this equation and the other equations indicates that this city center may be governed by an equation different from that for other cities studied. Because Tacoma was the only city included in the analysis with a population less than 600,000 persons, it may well represent another group of cities.

Some questions may be asked about the meaning and magnitude of the constant term of the equation. Physically, it is present because the observations indicate that the equation does not pass through the origin and represents one of the unknowns in the use of a regression analysis. The effect of the constant term on the estimates is generally small and the apparent wide difference between its value as determined in Philadelphia and Seattle is not as critical as the differences in the values of the respective coefficients.

CONCLUSIONS

This investigation has been able only to form an introduction to what may be a very profitable field of study. The results are such that it is possible to say that the number of people attracted to an area in a city's center appears to be closely related to the amount of floor space being used for various purposes in the section of the CBD considered. It seems that, for highway planning, it would be valid to use sound economic forecasts of future floor-space use in the central area as an index of the area's expected future attraction, and by means of equations similar to the ones developed, estimate the number of people likely to be attracted to the CBD zones.

Although these results cover only a limited range they show that there is a good deal of similarity among cities when the attraction of people to the CBD is considered. If more equations could be developed for cities in which O-D and floor-area studies have been made, it may be possible to formulate equations to suit other cities in which a comprehensive traffic study has not been performed which, of course, would be of great value in transportation planning.

The similarities among the equations for Philadelphia, Detroit, Baltimore and Seattle are so great that it seems reasonable to suggest at this stage that if such an equation is developed for a city in this population range it will change little as the city grows. Changes appear to occur in the amount and distribution of the floor area in use rather than in the trip generation rates.

One interesting result from the analysis is that the use of person movements, irrespective of mode of travel, has indicated great similarities between travel to the center of Philadelphia and Detroit. These similarities would have been masked by differences in automobile ownership and use in the two cities, and an apparent dominance of the central area in Philadelphia due to mass transportation facilities.

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Appendix A

STUDY FLOOR-SPACE CLASSIFICATION

Metropolitan Area	Retail	Service-Office	Manufacturing-Warehousing
Philadelphia	Retail	Wholesaling without stocks Business service Consumer service Hotels	Manufacturing Wholesaling with stocks Undetermined
Detroit	Retail business	Office building Parking lots Parking garages Institutions Utilities Hotels Terminals Open storage	Warehouses Light industry Heavy industry
Baltimore	Retail	Business service Consumer service Wholesale without stocks	Manufacturing Wholesale with stocks Unknown
Seattle	Retail	Hotels and recreation Eating places Automotive uses Banks and miscellaneous Business offices Public offices Institutional and organizational	Commercial Industrial Public Semi-public
Vancouver	Retail	Office Public Other	Industry and warehousing
Tacoma	Core retail Intensive retail Extensive retail	Office and services Consumer services Amusement and recreation Hotel Parking Public Semi-public	Warehousing Wholesale Manufacturing-industrial
Dallas	Classified from map	Parking space omitted	

Note: Residential and vacant space excluded from the analysis.

Appendix B

Philadelphia, All CBD Zones

Table 4 shows that about one-half of the areas are predicted by the regression equation with an error in excess of 30 percent. However, it can be seen that the zones with appreciable prediction error are actually the smaller generators, in all accounting for only one-quarter of the total person destinations in the center.

This analysis presented some problems because the boundaries of the blocks used in the floor-space study did not coincide in every case with the traffic zone boundaries. This meant that some O-D zones had to be grouped and as a result there was considerable variation in the land area of the zones and groups of zones used in the analysis. This variation appears to add to the error of prediction because of the greatly increased effect of the constant term in the equation on the smaller land areas. In the other cities considered, the zones were of a more uniform size from the point of view of land area. Although there is a wide variation in the amount and distribution of floor space in each zone, the predictions in the other cities are generally closer than in this case. It was thought that the great difference in the land area of the zones considered affected the regression analysis.

The coefficient of multiple determination indicates that 96 percent of the variation in person destinations can be explained on the basis of differences in the amounts of floor area in use in the zones. This estimate depends on the floor space and person destination variables being jointly normally distributed. This is difficult to assess but it appears that this coefficient may not be too misleading.

Detroit CBD

Table 5 indicates a good relationship between the variables. Use had to be made of the larger survey districts rather than zones, but only one district is considerably in error when attraction is explained by the equation. This district is situated on the edge of the area classed as CBD.

Baltimore CBD

Table 6 shows that although a relationship does exist, the accuracy of estimation is not as great as for the other cities. This is probably due to the time lag between the two surveys, although in Seattle, where a similar difference occurred, the errors are not as great. Two zones 0041 and 0051 show considerable error but again these are the smaller generators and are situated on the edge of the area classed as CBD.

Seattle CBD

Table 7 shows a well-developed relationship, the coefficient of multiple determination indicating that 96 percent of the variation is explained by the floor-space relationship. The area delimited as the CBD by the Murphy-Vance method was available for the city and could be compared with the results of the regression analysis. The only two zones falling completely outside the area were zones 006 and 008 which have the largest errors of estimation.

Vancouver CBD

Analysis for this city was complicated by the fact that manufacturing-warehousing space was given in the form of acres of site area (Table 8). The calculations made are based on the site area converted to square feet. This assumption is probably incorrect and must play some part in causing the constant in the regression equation to be positive whereas the other equations show negative constants. Because the negative constant is repeated so often and seems logical from a consideration of the curvilinear law, which it is thought would suit CBD fringe zones, this analysis seems to be in error.

TABLE 4

FLOOR SPACE; PERSON DESTINATIONS; ESTIMATED PERSON DESTINATIONS; AND ERROR IN ESTIMATE—PHILADELPHIA ALL CBD ZONES

REGRESSION EQUATION $\hat{Y} = 14\ 602 X_1 + 5\ 858 X_2 + 1\ 276 X_3 - 3470$

O-D ZONE	FLOOR SPACE 1000's Sq. Ft RETAIL X_1	SERVICE-OFFICE X_2	MANF'G.-WHSG X_3	O-D PERSON DESTINATIONS (24 hrs.) Y	EST'D PERSON DESTINATIONS (24 hrs.) $\hat{Y}$	$\hat{Y}-Y$	% ERROR
0001, 0002	1809	11,118	1473	88,490	89,950	+1460	+ 16
0003	41	2130	144	28,860	9,790	−19,020	− 66
0005, 0006	4366	6811	2290	103,690	103,100	− 690	− 06
0007, 0008	2975	3818	2633	77,200	65,700	−11,500	− 15
0043	23	781	0	3700	1440	2260	− 61
0042	15	165	12	1790	−2270 *		
0041	105	160	87	3700	− 980 *		
0063	86	729	612	2540	2840	+ 300	+ 12
0064	97	431	257	2180	800	−1300	− 60
0009	2684	441	1706	36,590	40,480	+3890	+ 11
0061	71	658	196	8340	1670	−6670	− 80
0062	174	1172	196	6260	6190	− 70	− 11
0027, 0029, 0032	906	3581	604	26,510	31,510	+5000	+ 19
0045	346	1484	281	4550	10,630	+ 6080	+ 134
0047	231	1067	246	3850	6470	+ 2620	+ 68
0082	92	2783	1642	13,660	16,270	+ 2610	+ 19
0091	843	1921	2351	17,220	23,090	+ 5870	+ 34
0073	300	491	1502	3270	5700	+ 2430	+ 74
0026, 0028, 0031	668	1897	628	10,950	18,200	+ 7250	+ 66
0023, 0025	558	1703	252	9540	14,980	+ 5440	+ 57
0044	348	250	370	1970	3550	+ 1580	+ 80
0046	383	226	325	1940	3860	+ 1920	+ 99
0081	629	755	860	5500	11,230	+ 5730	+ 104
0052	440	2360	3779	23,430	21,600	− 1830	− 8
0053	261	1158	4234	6970	12,530	+ 5560	+ 80
0051	242	223	565	2190	2090	− 100	− 4·5
0092	147	859	2702	6200	7160	+ 960	+ 15
0072	154	277	227	2030	690	− 1340	− 66
0071	205	333	1390	4080	3250	− 830	− 20
0022, 0024	176	344	150	2690	1310	− 1380	− 51
0021	117	211	76	2450	− 430 *		

Variance of Estimate $S^2(\hat{y}) = 30{,}178{,}700$

Standard Error of Estimate $S(y) = 5490$ Person Destinations

Coefficient of Multiple Determination $R^2 = 0\ 960$

	X_1	X_2	X_3	K
95% Confidence Range of Equation Parameters	11 873	4 709	− 0 693	+2120
	17 331	7 007	3 245	−9080

TABLE 5

FLOOR SPACE; PERSON DESTINATIONS; ESTIMATED PERSON DESTINATIONS; AND ERROR IN ESTIMATE—DETROIT CBD ZONES

REGRESSION EQUATION :— $\hat{Y} = 13.918 X_1 + 4.613 X_2 + 1.717 X_3 - 2280$

O–D DISTRICT	FLOOR SPACE 1000's Sq. Ft			O-D PERSON DESTINATIONS (24 hrs)	EST'D PERSON DESTINATIONS (24 hrs)	$\hat{Y} - Y$	% ERROR
	RETAIL X_1	SERVICE –OFFICE X_2	MANU'F. -WAREHOUSING X_3	Y	$\hat{Y}$		
00	5400	2721	86	85,850	85,580	−270	− 0.3
01	2454	14,162	1573	99,670	99,900	+230	+ 0.2
11	480	3259	3348	25,260	25,180	− 80	− 0.3
12	440	1494	1154	8,210	12,710	+4500	+55
13	140	761	10	2,760	3,200	+440	+16
15	193	1968	789	11,800	10,840	−960	− 8
17	426	2680	721	19,030	17,250	−1780	− 9
19	102	1330	1578	10,000	7,980	−2020	−20

VARIANCE of ESTIMATE $S^2(\hat{Y}) = 7,804,000$

STANDARD ERROR of ESTIMATE $S(\hat{Y}) = 2,790$ PERSON DESTINATIONS

COEFFICIENT of MULTIPLE DETERMINATION $R^2 = 0.997$

	X_1	X_2	X_3	K
95 % CONFIDENCE RANGE	12.086	3.864	−1.392	+ 6180
of EQUATION PARAMETERS	15.750	5.362	4.862	−10740

TABLE 6

FLOOR SPACE; PERSON DESTINATIONS; ESTIMATED PERSON DESTINATIONS; AND ERROR IN ESTIMATE—BALTIMORE CBD

REGRESSION EQUATION — $\hat{Y} = 12\,871 X_1 + 4\,524 X_2 + 1\,343 X_3 - 1080$

O-D ZONE	FLOOR SPACE: 1000's Sq Ft			O-D PERSON DESTINATIONS (24 hrs)	EST'D PERSON DESTINATIONS (24 hrs)	$\hat{Y}-Y$	% ERROR
	RETAIL X_1	SERVICE-OFFICE X_2	MAN'F'G-WHSG. X_3	Y	$\hat{Y}$		
010	289	888	1456	9,780	8,670	−1110	− 11
011	1356	1245	1538	19,410	23,770	+4360	+ 22
012	596	1607	1538	20,300	15,990	−4310	− 21
020	661	2739	689	21,230	20,750	− 480	− 2
021	88	1348	1384	9,910	8,040	−1870	− 19
022	258	1562	70	15,300	9,440	−5860	− 38
023	106	430	269	3,670	2,680	+ 990	+ 27
030	1323	852	177	27,830	20,180	−7650	− 27
031	1203	1504	143	18,110	21,500	+3390	+ 19
040	194	1723	53	7,570	9,310	+1740	+ 23
041	140	1445	721	2,620	8,260	+5640	+215
051	560	877	459	3,460	10,880	+7420	+214

VARIANCE of ESTIMATE $S^2(\hat{Y}) = 31,720,600.$ STANDARD ERROR of ESTIMATE $S(\hat{Y}) = 5,630$ PERSON DESTINATIONS

COEFFICIENT of MULTIPLE DETERMINATION $R^2 = 0.667$

	X_1	X_2	X_3	K
95% CONFIDENCE RANGE	5.046	−2.005	−5.193	+4810
of EQUATION PARAMETERS	20.818	10.953	7.859	−30,580

TABLE 7

FLOOR SPACE; PERSON DESTINATIONS; ESTIMATED PERSON DESTINATIONS; AND ERROR IN ESTIMATE—SEATTLE CBD

REGRESSION EQUATION :— $\hat{Y} = 13.678 X_1 + 4\ 382 X_2 + 0.152 X_3 - 200$

O-D ZONE	FLOOR SPACE 1000's Sq Ft RETAIL X_1	SERVICE -OFFICE X_2	MANU'F -WAREHOUSING X_3	O-D PERSON DESTINATIONS (24 hrs) Y	EST'D. PERSON DESTINATIONS (24 hrs) $\hat{Y}$	$\hat{Y} - Y$	% ERROR
012	138	1200	320	5,800	6,990	-1190	-20
013	1248	678	73	22,760	19,850	+2910	+13
014	1118	1374	112	19,850	21,130	-1280	- 6
015	62	870	148	4,160	4,480	- 320	- 8
016	1380	940	25	21,110	22,800	-1690	- 8
017	370	2356	23	16,160	15,190	+ 970	+ 6
002	105	629	397	3,420	4,050	- 630	-18
003	191	2096	0	11,750	11,600	+ 150	+ 1
004	70	2143	0	9,170	10,150	- 980	-11
005	44	1276	238	6,920	6,030	+ 890	+13
006	29	328	530	2,960	1,710	+1250	+42
007	25	1702	22	8,950	7,600	+1350	+15
008	22	591	191	1,340	2,720	-1380	-103

VARIANCE of ESTIMATE $S^2(\hat{Y}) = 2{,}539{,}700$ STANDARD ERROR of ESTIMATE $S(\hat{Y}) = 1590$ PERSON DESTINATIONS

COEFFICIENT of MULTIPLE DETERMINATION $R^2 = 0\ 965$

	X_1	X_2	X_3	K
95% CONFIDENCE RANGE	11 077	1.781	-10.637	+5720
of EQUATION PARAMETERS	16.279	6.983	+10.941	-6110

TABLE 8

FLOOR SPACE; PERSON DESTINATIONS; ESTIMATED PERSON DESTINATIONS; AND ERROR IN ESTIMATE—VANCOUVER CBD

REGRESSION EQUATION: $\hat{Y} = 14\ 322 X_1 + 10{\cdot}534 X_2 + 3\ 670 X_3 + 1560$

O-D ZONE	FLOOR SPACE: 1000's Sq Ft. RETAIL X	SERVICE-OFFICE X	MAN'FG-WHSG. X	O-D PERSON DESTINATIONS (24 hrs.) Y	EST'D. PERSON DESTINATIONS (24 hrs.) $\hat{Y}$	$\hat{Y}-Y$	% ERROR
900	382	3692	44	46,900	46080	- 820	- 17
901	1674	2124	87	48 640	48,230	- 410	- 0·8
902	43	142	44	4400	3830	- 570	- 13
910	176	1273	610	18,530	19,730	+1200	+ 6
911	3	513	0	1860	7,000	+5140	+276
920	321	690	566	14,220	15,500	+ 1280	+ 9
921	4	45	392	2 630	3530	+ 900	+ 34
930	10	88	1350	12,580	6020	-6560	- 52
940	86	503	174	14,110	8730	-5380	- 38
950	1294	1348	1176	39,460	38,610	- 850	- 2
951	443	717	1525	16,450	21,050	+4600	+ 28

VARIANCE of ESTIMATE $S^2(\hat{Y}) = 15{,}342{,}400$ STANDARD ERROR of ESTIMATE $S(Y) = 3920$ PERSON DESTINATIONS

COEFFICIENT of MULTIPLE DETERMINATION $R^2 = 0{\cdot}963$

	X_1	X_2	X_3	K
95% CONFIDENCE RANGE	8·126	7 223	- 1·887	+ 10,420
of EQUATION PARAMETERS	20·518	13·845	9·227	- 7300

This is a problem encountered in any use of a multiple regression technique when the line of best fit may produce coefficients which are meaningless from a common-sense point of view. If more observations were available the resulting equation might be quite different from the one found in this analysis.

Tacoma CBD

With only five observations to work from, the results shown in Table 9 cannot be regarded as significant. An equation of this type, with four unknowns, can be calculated to fit perfectly four observations. Therefore, with only five observations, the regression equation found from the analysis may be so influenced by errors in the observations that it is completely misleading as a guide to the "true" relationship. The large negative coefficient on manufacturing-warehousing floor space is obviously incorrect. The comments made with regard to the positive constant given in the notes to Table 8 apply also to the constant and negative coefficient in this equation.

Dallas CBD

Table 10 shows a floor-space estimate based on a land-use map marked with building heights. To produce a meaningful area in the service-office classification, parking space was eliminated from the floor space. The results show only that some relationship is present between person destinations and floor space and that the general form of the equation appears satisfactory for this city.

TABLE 9

FLOOR SPACE; PERSON DESTINATIONS; ESTIMATED PERSON DESTINATIONS; ERROR IN ESTIMATE—TACOMA CBD ZONES

REGRESSION EQUATION — $\hat{Y} = 7\,709X_1 + 2\,493X_2 - 17\,698\,X_3 + 3590$

O-D ZONE	FLOOR SPACE· 1000's Sq Ft RETAIL X_1	SERVICE - OFFICE X_2	MAN FG. -WAREHOUSING X_3	O-D PERSON DESTINATIONS (24 hrs) Y	EST'D PERSON DESTINATIONS (24 hrs) $\hat{Y}$	$\hat{Y} - Y$	%ERROR
000	226	902	78	6450	6200	-250	— 3.8
001	100	719	29	4610	5640	+1030	+ 22
002	1174	1025	63	13,540	14,050	+ 510	+ 3.7
003	300	726	133	6970	5360	-1610	-23
004	218	319	194	2360	2630	+270	+16

VARIANCE of ESTIMATE $S^2(\hat{Y}) = 6300$

STANDARD ERROR of ESTIMATE $S(\hat{Y}) = 80$ PERSON DESTINATIONS

COEFFICIENT of MULTIPE DETERMINATION $R^2 = 0{\cdot}997$

	X_1	X_2	X_3	K
95% CONFIDENCE RANGE	5 676	-2 589	-0·672	+6470
of EQUATION PARAMETERS	9 742	7 575	-34 724	+ 700

TABLE 10

FLOOR SPACE; PERSON DESTINATIONS; ESTIMATES PERSON DESTINATIONS; AND ERROR IN ESTIMATE—DALLAS CBD

REGRESSION EQUATION:— $\hat{Y} = 16\ 191 X_1 + 3\ 546 X_2 + 12\ 652 X_3 - 8570$

O-D ZONE	FLOOR SPACE 1000's Sq Ft			O-D PERSON DESTINATIONS (24 hrs)	EST'D PERSON DESTINATIONS (24 hrs)	$\hat{Y}-Y$	% ERROR
	RETAIL X_1	SERVICE -OFFICE X_2	MANU'F -WAREHOUSING X_3	Y	$\hat{Y}$		
01	509	740	874	18,380	13,350	−5030	− 27
02	15	404	546	3,840	10	−3834	−100
03	344	289	316	3,010	2,020	− 990	− 33
04	1474	5674	183	40,130	37,730	−2400	− 6
05	243	1558	1071	11,730	14,440	+2710	+ 23
06	940	2577	356	14,870	20,290	+5420	+ 36
07	676	542	114	3,070	5,740	+2670	+ 87
08	1499	1979	0	23,730	22,720	−1010	− 4
09	181	615	857	4,940	7,380	+2440	+49

VARIANCE of ESTIMATE $S^2(\hat{Y}) = 19{,}504{,}600$

STANDARD ERROR of ESTIMATE $S(\hat{Y}) = 4{,}420$ PERSON DESTINATIONS

COEFFICIENT of MULTIPLE DETERMINATION $R^2 = 0\ 920$

	X_1	X_2	X_3	K
95 % CONFIDENCE RANGE	0 392	0 413	−3 905	+14,690
of EQUATION PARAMETERS	32 774	7 505	29 209	−33,670