Intracity Traffic Movements

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● WITHIN the past decade, the daily travel habits of urban populations have been intensively studied by a host of investigators. Sociologists, economists, engineers, politicians, and many others have all found reasons to investigate specific aspects of intracity travel and the problems of street and terminal capacity which it creates. Much serious work has been done by persons seeking solutions to specific problems or making intensive study of a particular urban community. Few researchers have attempted to discover the characteristics of urban travel that are common to all communities.

About 5 years ago, a research project was set up at the Yale Bureau of Highway Traffic to investigate the fundamental nature of urban travel and to devise practical techniques for the measurement of characteristics which might be identified. Since this research was begun, a great deal has been learned about some aspects of intracity travel. Needless to say, a great deal still remains to be found out. The Yale Bureau studies, soon to be published, constitute a voluminous and detailed report. This paper constitutes a synopsis of the studies on automobile travel within the urban limits of modern American cities.

The principal source materials for these investigations have come from the home-interview origin-destination surveys cosponsored by the Bureau of Public Roads and various state and city agencies since 1944. About a hundred such studies have been made throughout the United States within the past 10 years.

Considerable time and effort was devoted to an evaluation of these home-interview data prior to using them for an analysis of urban-travel characteristics. Trip tabulations and other home-interview materials were obtained from about 60 cities, and studies which appeared to be most complete and which required the least adjustment were selected for further analysis. Twenty post-war studies were picked for the initial investigations.

TOTAL INTERNAL TRAVEL

Initial stages of the urban travel studies were based on the broadest possible investigations. The gross number of internal trips performed by all members of each urban community was determined, disregarding travel mode, and the overall trip volumes for all 20 cities plotted against community size (Fig. 1). Total internal travel in all cities appears to be directly proportional to urban population without regard to the geographic location of the community or the year of study, although the correlation found is far from perfect.

INTERNAL WORK TRIPS

At the second level of investigation, work trips were segregated from trips made for other purposes. The argument for doing so was based on the finding that work trips were more-completely reported in the home interviews than trips for other purposes. Work trips also constitute the largest category of trips by purpose. Furthermore, the labor force in an urban population constitutes about 40 percent of the residents in most census tracts and is, therefore, distributed throughout most of the area in direct proportion to population distribution. If about the same proportion of the labor force in each city can be expected to report to work each day, it would seem that work trips should be made in direct proportion to the size of the population pool. Investigation of the twenty cities show that such is indeed the case (Fig. 2). Work trip volume is found to be more consistently related to city size than is the over-all volume of internal travel generated by urban populations (Fig. 1).

INTERNAL AUTO-DRIVER WORK TRIPS

Work trips were next related to mode of travel to and from place of employment (auto driver or transit rider). When the total daily volume of internal work trips was plotted against city size, a rather wide variation in average per capita trips was found for auto

TABLE 1

TWENTY HOME-INTERVIEW ORIGIN-DESTINATION STUDIES

Population, Dwelling Unit Occupany, Vehicle Registration

No.	City and State	Year of Study	Pop. of Study Area (thous.)	Av. No. Persons Per Dwg. Unit	Private Autos Owned per 1000 pop.
1.	Minneapolis, Minn.	1949	585	3.0	255
2.	Seattle, Washington	1946	519	2.8	288
3.	Portland, Oregon	1946	453	3.0	231
4.	St. Paul, Minnesota	1949	331	3.1	235
5.	Grand Rapids, Mich.	1947	221	3.4	239
6.	Salt Lake City, Utah	1946	197	3.4	194
7.	Tacoma, Washington	1948	139	2.9	253
8.	Spokane, Washington	1946	138	2.9	215
9.	Tucson, Arizona	1948	127	3.3	260
10.	Lansing, Michigan	1946	123	3.4	247
11.	Albuquerque, N.M.	1949	116	3.3	237
12.	Saginaw, Michigan	1948	113	3.5	239
13.	Madison, Wisconsin	1949	104	3.1	243
14.	Duluth, Minnesota	1948	97	3.0	204
15.	Johnstown, Pa.	1949	88	3.8	158
16.	Muskegon, Mich.	1946	84	3.6	226
17.	Kalamazoo, Mich.	1946	72	3.2	238
18.	Bay City, Mich.	1948	69	3.5	229
19.	Sharon-Farrell, Pa.	1949	48	3.6	195
20.	Superior, Wisconsin	1948	34	3.2	172

driver travel (Fig. 3). Similar variation was found for the ratio of transit work trips to population in cities under 200,000 (Fig. 5). A remarkable correlation of transit work-trip-ratio to city size was found for cities larger than 200,000. The apparent stability of the curve shown is based on so few data, however, (only six cities) that it should be viewed with caution.

An attempt was next made to find the principal cause of work-trip deviations by mode. Inasmuch as total work trips (Fig. 2) are generated in direct proportion to population, variations by mode must be due to differences in the relative attractiveness of transit and auto travel in different cities. This could mean poor terminal facilities, relatively low auto ownership, especially convenient and attractive mass transportation, or a combination of these and other factors.

Since car-ownership data were available for each city, the effect of car ownership was tested against variations from the curves fitted to data in Figures 3 and 5.[1] From

[1] This is a graphic correlation technique suggested by Ezekiel. Deviations from the freehand lines of estimate in Figures 3 and 5 have been computed as a percentage of the value represented by the line, and the percentage deviations plotted against the ratio of cars to people in each city. If that ratio is the most-important cause of deviation from the original curve, the new series of points should line up in such a way that a curve can be fitted to them which will materially reduce the total amount of deviation found in the first instance. Such freehand curves have been fitted to plotted variations in Figures 4 and 6. The broken lines of Figure 4 represent a range of 10 percent above and below the values represented by the fitted curve. See: Ezekiel, Mordecai, "Short-Cut Methods of Determining Net Regression Lines and Curves," Chapter 16, Methods of Correlation Analysis, John Wiley and Sons, New York, 1930, pp. 229-241.

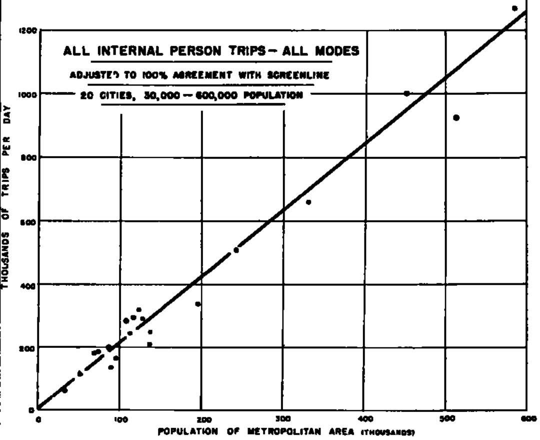


Figure 1.

these tests, it was clearly shown that the ratio of cars to population is indeed an important factor in the choice of travel mode to and from work. Figure 4 shows that most of the variation in auto trips to work is a function of car ownership. The deviations plotted in Figure 6 represent transit riders for only those cities under 200,000 population. High vehicle ownership is seen to be an important negative factor in the generation of work trips but is clearly not the only factor, aside from city size, which influences work trips by transit.

ALL INTERNAL CENTRAL BUSINESS DISTRICT TRIPS

Thus far, the studies have shown that city size has a consistent effect on the generation of travel within a city, being directly related to volume of trips generated by purpose (work) and by mode of travel (auto or transit). Another area worth investigating is that of land use.

Figure 7 shows the attractive power of the central business district in each of the 20 cities for all modes and purposes of travel.[2] A remarkably uniform pattern of central-business-district trip generation is shown for the 20 cities. A free-hand curve fitted to the data appears to show that the central business district attracts visitors from within the city at an increasing rate as cities increase in size. The data do not include walking trips, however, which are of considerable importance in small cities but lose importance as cities become larger and more spread out. It is also likely that the small number of cities in the range 200,000 to 600,000 are not a fair sample, since investigations of still larger cities (not shown) show that the central business district attracts internal trips at a decreasing rate as metropolitan area populations become very large.

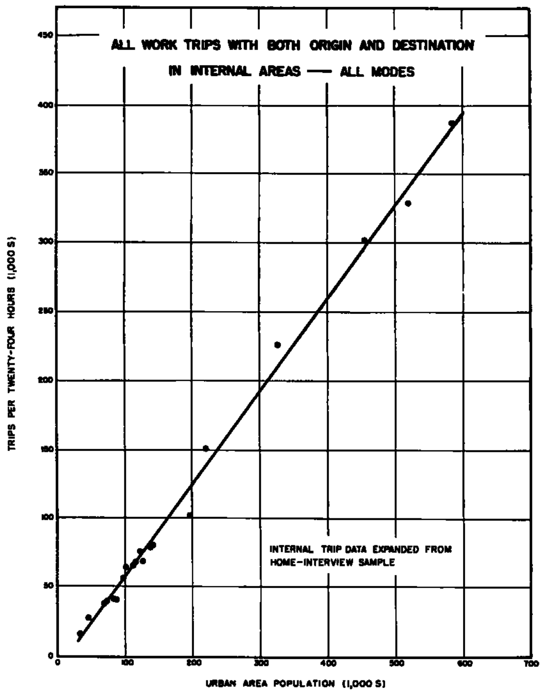


Figure 2.

[2] Initial investigations of central-business-district travel were based on trips generated in the business districts described in each city survey report. Wide discrepancies in relative trip attraction in some cities were traced to overzoning the central business district to include several times the area of greatest trip attraction. An effort was then made to identify the "core" area in each downtown business district. The core, as defined for the parking surveys and as used here, consists of a unified grouping of blocks, nearly all of which generate more auto trips than can be accommodated by parking spaces at curbs or offstreet in the blocks. Since trip data are available for study on a "zone" basis, it has been necessary to include small amounts of excess area where zone limits did not coincide with core area limits. The generation of trips in these marginal blocks is so low per unit of area, when compared to the core, that relatively little discrepancy should be expected from this source.

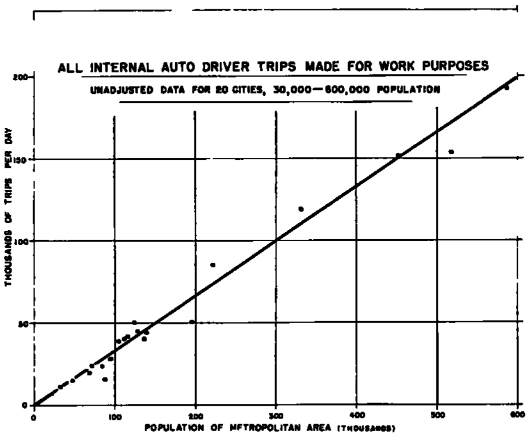
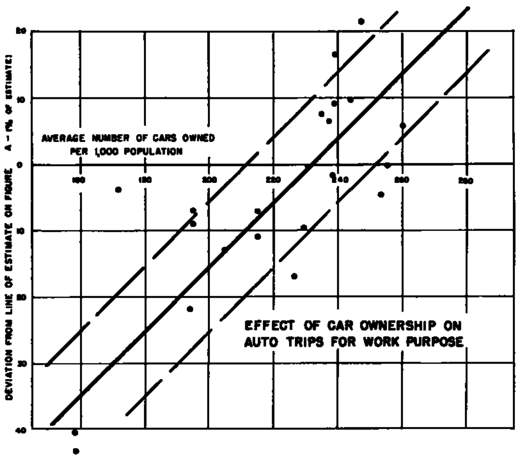


Figure 3.



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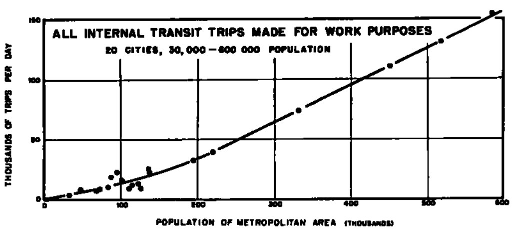

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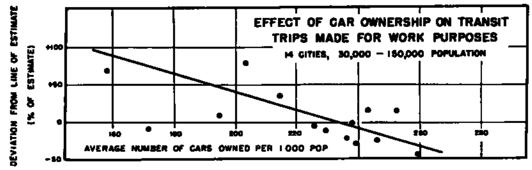

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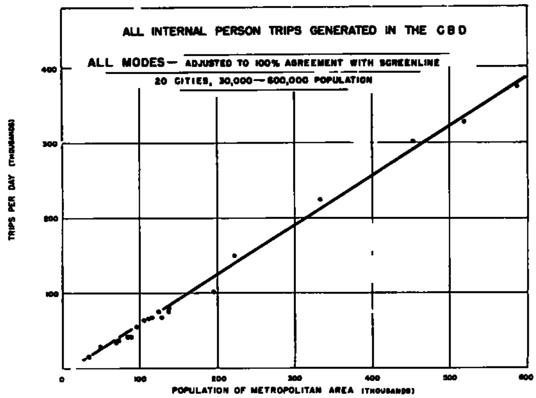


Figure 7.

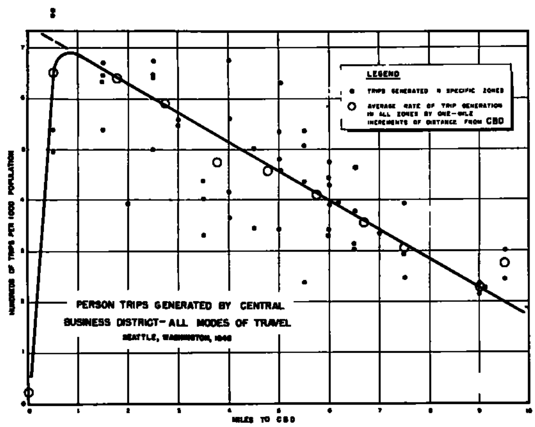


Figure 8.

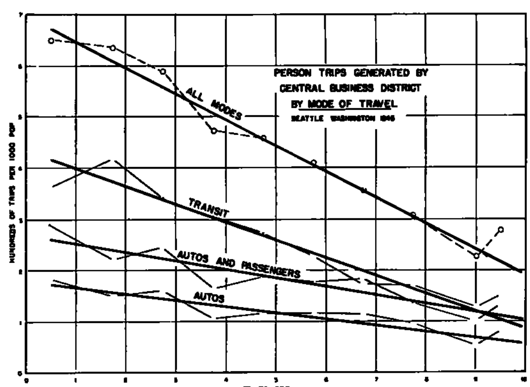


Figure 9.

DETAILED EXAMINATION OF CENTRAL BUSINESS DISTRICT TRIP DATA

At this point in the investigations, it became necessary to make a much-more-detailed analysis of the origin-destination data. Because the analyses are very involved when areas are studied by zones instead of on an overall basis, it was found desirable to reduce the number of cities studied. In doing so, however, the range of city size has been increased by adding

TABLE 2

ORIGIN-DESTINATION STUDIES OF THE CENTRAL BUSINESS DISTRICT

City	Year of Survey	Met. Area pop. (thous.)	CBD Core	Trips Generated Auto Dr.	Auto and Taxi Pass.	Transit	Total
Washington, D. C.[a]	1948	1,110	Sector 0	101,120	(Taxi 24,013) 93,278	302,608	497,006
Seattle, Wash.	1946	519	District 5 and 6-Zones	50,948	(Taxi 13,085) 47,500	177,670	275,118
			002-005, 007 012-017	72,073	36,288	146,538	254,899
Portland, Oregon	1946	453	Zones 023, 031-036, 041, 042, 053	71,173	34,044[3])	120,083	225,300
Honolulu, T. H.	1947	214	Zones 001, 002, 011, 012, 021, 022	33,429	16,714[3])	42,853	92,996
Wilmington, Del	1948	181	Zones 015, 021-025	26,939	17,006	41,707	85,652
Tacoma, Wash.	1948	139	District 00	27,194	11,127	27,818	66,139
Albuquerque, N. M.	1949	116	Zones 000, 001	26,433	15,939	16,984	59,410
Bay City, Mich.	1948	69	Zone 144	23,784	12,687	8,922	45,393
Kenosha, Wis.	1950	56	Zones 111 and 121	16,107	7,610	7,720	31,437

[a]Data for all of Sector "0" have been used to represent the District of Columbia. Districts "5" and "6" within the sector represent the principle retail areas and generate a little more than half of Sector "0" volume. Government offices are the principle generators in the rest of the sector and while they may or may not represent a normal central business district function, the lumping of all sector "0" trip generation results in a trip volume that is approximately the amount expected from extrapolation of the line of estimate on Figure 7. Figure 7 was prepared from data limited to cities under 600,000 pop. - none of them more than half the size of Washington at the time of its study and can only be applied experimentally to Washington data. Data from other large cities will have to be tested before this extension of the curve can be evaluated.

a larger city (Washington, D. C.) and a smaller city (Kenosha, Wisconsin) to the list.

Another consideration which came to mind at this time related to the shape of a city's pattern of growth. If the study was restricted to cities which were so located that they had developed equally in all directions from the central business district, would travel characteristics and other relationships which might be derived from study of those cities apply to communities of less regular shape? To avoid this uncertainty, a diverse group of cities was selected for study with the hope that any characteristics common to the group would be representative of all cities within a similar range of size. The cities selected for these studies are listed in Table 2.

CENTRAL-BUSINESS-DISTRICT TRIPS RELATED TO LENGTH OF TRIP

Since the central business district seems to attract trips from within the metropolitan area in direct proportion to the size of the population pool, it might be expected that such trips are uniformly distributed throughout the urban populace. Such is not the case, however. Figure 8 is a plot of trips generated in the central business district.[3]

The daily rate of central-business-district trip generation per 1,000 population in Seattle is shown to deteriorate rapidly as distance from the central business district increases. Populations 9 miles from the central business district generate travel at only a third of the rate for populations at 1 mile. The rate of trip generation appears to depreciate uniformly with distance between those points.

Investigations of central business district trips versus distance from central business

[3]Distances were measured along the shortest route by existing streets between the approximate center of the central business district and the center of population in each zone. Distances were rounded to the nearest ½ mile and plotted as shown. Data were then combined for travel between central business district and all zones at each increment of distance. Average rates of trip generation were computed by 1-mile increments, and these averages were plotted. A free-hand regression curve was then fitted to the plot of 1-mile averages, and the deviations from this line subject to statistical examination. All points are within acceptable range of the regression curve, considering the number of trips and size of sample involved in each case. Within a mile of the central business district, walking trips account fot the decline in rate of trip generation by car and transit.

district for a number of other cities (not illustrated) disclose similar behavior patterns. In every case the rate of trip generation decreases with distance. Even so, it is difficult to reconcile the curve shown in Figure 7 with such a variable rate of trip generation related to travel distance as is shown here.

CENTRAL-BUSINESS-DISTRICT TRIPS RELATED TO LENGTH AND MODE OF TRAVEL

When trips generated in the central business district for all purposes are plotted by mode against length, several interesting relationships appear. First, trips by each mode

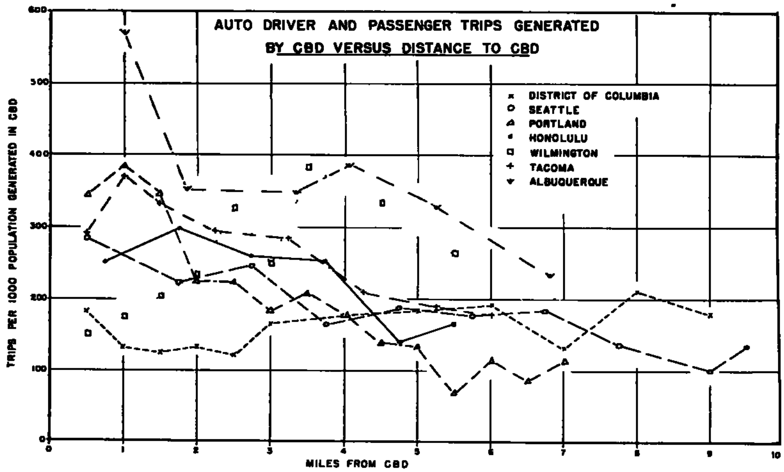


Figure 10.

tend to be generated at a lower rate as distance from the central business district increases. However, trips by transit drop off much-more rapidly than auto-driver trips. There are several reasons why this is so. Study of the population-vehicle ownership ratio zone by zone shows that fewer cars are owned per thousand population near the central business district than in areas further out. Furthermore, transit lines do not give the same amount of service at the outskirts of urban population that they provide near the center, making a higher proportion of the population dependent on cars as distance from the central business district increases. Also, the travel time required by bus or streetcar is less important for short trips originating near the central business district than for longer trips from the outskirts where the rider experiences longer walking distances, longer headways, and many more stops between points of boarding and alighting.

Figure 9 illustrates the patterns of central-business-district trip generation by transit, auto drivers, and drivers and passengers in Seattle, Washington. At 9½ miles, transit riders are generated at only a fourth the rate at which they are generated a mile from the central business district. On the other hand, at 9 miles auto drivers and auto drivers and passengers are generated at half the rate experienced at 1 mile. However, auto drivers and passengers amounted to only two thirds of the volume of transit traffic at a mile, and transit riders were still equal in numbers to drivers and passengers at 9 miles.

In other cities the ratio of auto riders to transit riders is different than that shown for Seattle, but the principles of trip generation are similar. In large cities, transit trips generated near the central business district may be several times the volume of auto riders. In smaller cities, the automobile may be much-more important than transit. In fact, the auto is much more important in the city of Seattle now than at the time of the origin-destination survey in 1946, due to a considerable increase in auto ownership throughout the city.

Figure 10 shows auto-driver-and-passenger data for seven metropolitan areas, ranging in size from 116,000 to more than a million in population. The cities represent a wide variety of geographic locations and city types. Yet, with the exception of Wilmington, Delaware, auto driver and passenger trips are generated by the central business district according to a fairly consistent pattern. At all distances from the central business district, the smallest community (Albuquerque) generates the highest ratio of central-business-district auto trips per unit of population. There is a tendency for auto travel per unit population generated in the central business district to decline as cities become bigger, especially in zones near the central business district. It is clear, though, that other conditions modify this tendency, especially in the case of Wilmington.

RATIO OF POPULATIONS TO CARS VERSUS DISTANCE FROM CENTRAL BUSINESS DISTRICT

Much of the apparent discrepancy in Figure 10 may be explained by a study of car ownership ratios shown for nine cities in Figure 11. Residents of Wilmington, Honolulu, and the Washington, D. C., metropolitan areas are shown to possess few cars in zones close to the central business district, accounting, in part, for the low rate of auto travel generated in those zones. Car ownership increases rapidly with distance. This pattern of car ownership provides a quality of auto-travel service just the reverse of that made available by mass-transportation facilities which are focused on the central business district and give most-efficient service to nearby zones.

The population-vehicle ratio tends to level off at about 4 miles, ownership increasing at a slow rate beyond that distance. Most of the data shown were collected from 1946 through 1949. Despite a considerable increase in automobile registration throughout the country during these years, there is remarkably close agreement between the curves

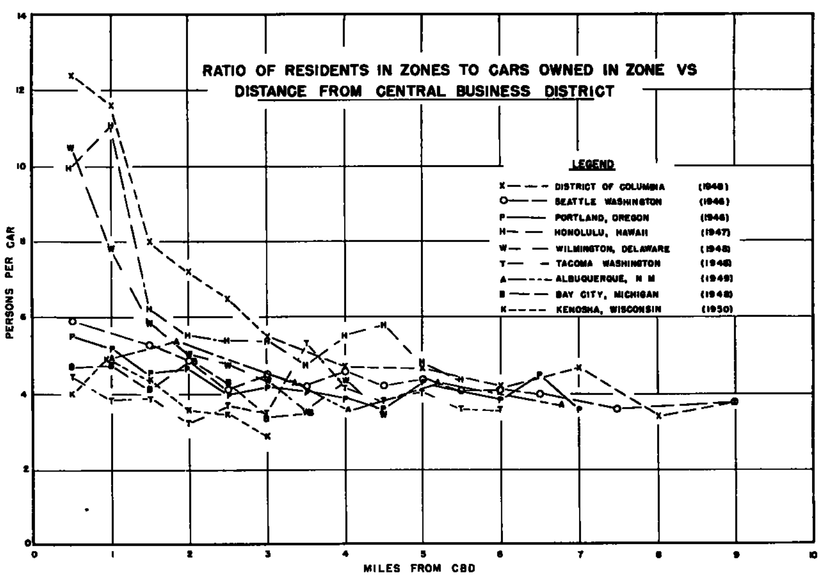


Figure 11.

beyond 4 miles (3.5 to 4.5 persons per car). An even-greater increase in registration has taken place in the 5 years, 1949-1954, and the ratios shown in Figure 11 have undoubtedly been modified.

Registration in the peripheral areas beyond 4 miles are generally as high or higher than registrations for the state as a whole, excepting in those locations where the urban area itself constitutes a large proportion of the state's total population. Data for all cities except Washington are shown in Table 3.

Note that outlying Seattle had a lower population-vehicle ratio than the State of Washington in 1946. Since then the ratio of persons to cars in the state has dropped about 50 percent. Seattle residents have undoubtedly contributed to the drop by acquiring more cars. Other states have increased registrations at about the rate shown for Washington.

TABLE 3

City	Year of Study	[a]Pers/car 4 mi. and beyond	Persons per car in State Year of Study	Persons per car in State 1952
Seattle, Washington	1946	4.00	4.45	3.50
Portland, Oregon	1946	4.20	3.90	2.45
Honolulu, Hawaii	1947	5.35	6.60	4.10
Wilmington, Delaware	1948	3.95	4.65	3.30
Tacoma, Washington	1948	3.85	3.75	3.00
Albuquerque, New Mexico	1949	3.70	4.30	3.70
[a] Bay City, Michigan	1948	3.76	3.53	2.96
[a] Kanosha, Wisconsin	1950	3.33	3.57	3.48

[a] The peripheral area for Bay City and Kenosha begins at 2.5 miles.

CENTRAL - BUSINESS - DISTRICT TRIPS PER CAR VERSUS DISTANCE FROM CENTRAL BUSINESS DISTRICT

A series of smoothed curves for nine cities, drawn over plotted data, are shown in Figure 12 to illustrate the rate at which the average automobile generates trips in the central business district at various distances.

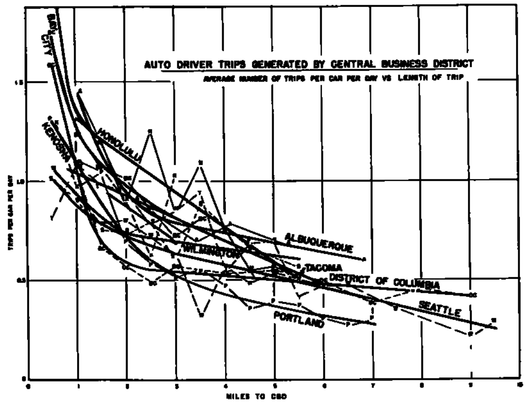


Figure 12.

Note that cars garaged near the central business district in nearly all of these cities generate a much-higher average volume of trips than do cars from more remote zones. The rate of trip generation declines precipitately to a distance of 1½ to 2 miles and then assumes a more gradual rate of decrease. This transition requires special study to determine how its effect on trip generation can be measured.

In some respects these curves reflect the car ownership ratios illustrated in Figure 11. Where the number of cars owned is small in proportion to the number of residents, there is unusual pressure on car owners to make use of their vehicles. Under these conditions the average car may make twice as many trips into the central business district as vehicles in other cities where ownership is greater.

Furthermore, if transit service is relatively poor, such as is likely in communities not yet large enough to support a well integrated transit system, the auto is called on to perform a higher proportion of the daily travel. This would account for a high rate of trip generation even when car ownership is high, as in Bay City and Kenosha.

RELATION OF CENTRAL BUSINESS DISTRICT TO METROPOLITAN AREA POPULATION

The ratio of persons to cars, to length of trip, and to trips per car account for much of the variability of auto-trip attraction to the central business district. Data for cities like Wilmington and Honolulu are still not explained in a satisfactory manner, however. In seeking another measure to explain the remaining discrepancies, it was noted that the relative concentration of population with regard to the central business district in each of the nine metropolitan areas was extremely variable.

Figure 13 shows the relative amount of metropolitan-area population living at any distance from the central business district. In cities which have been able to develop symmetrically around the central business district, such as Wilmington and Washington, D. C., populations are quite compact. In cities forced to develop in a lopsided fashion because of topographical restrictions, such as Honolulu and Seattle, population is spread over a greater distance and is not concentrated so heavily around the central business district. This characteristic of population concentration is not necessarily related to density. There are simply more acres available for development at each range of distance in symmetrical cities than are usable in asymmetrical areas. Since the volume of travel generated between the central business district and residential zones is modified by travel distance, it is clear that population concentration is an important factor in trip generation.

CORRELATION OF VARIABLES AFFECTING AUTO TRAVEL TO AND FROM CENTRAL BUSINESS DISTRICTS

Four important independent variables have been identified which relate to the generation of internal auto trips in the central business districts of cities under ½ million population. The average number of trips made to and from the central business district each day by each car garaged in the metropolitan area is related to the average distance of travel (trip length), the number of persons per car in each area (population-vehicle ratio), the proportion of the urban area population that is concentrated within various increments of distance from the central business district (population compactness), and the total number of people resident in the metropolitan area (city size).

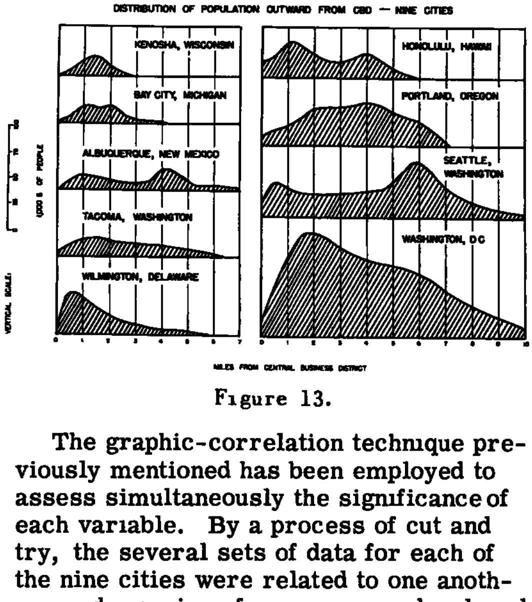


Figure 13.

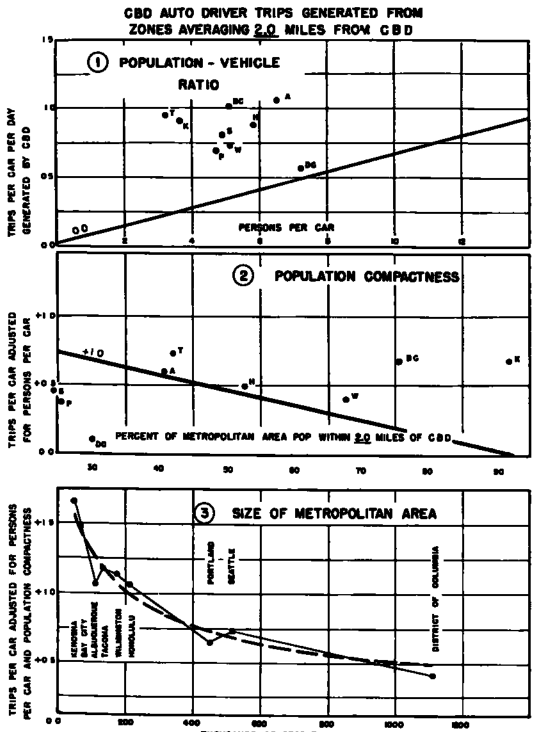
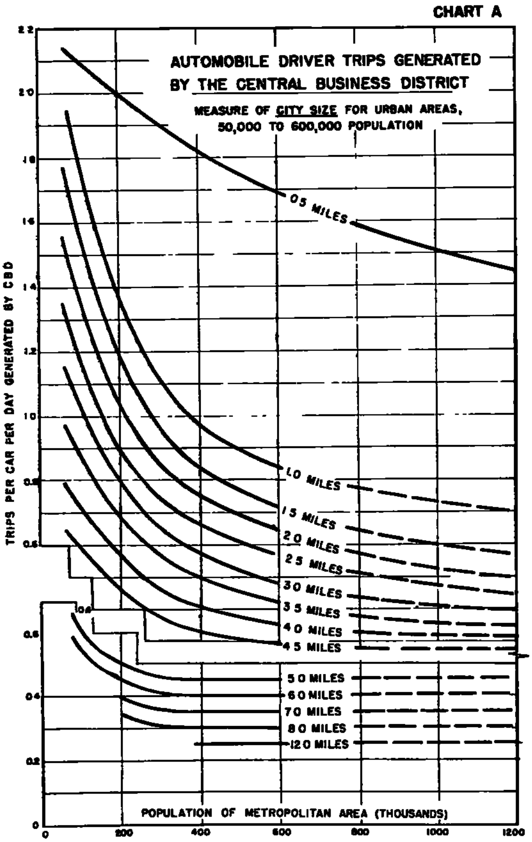


Figure 14.

The graphic-correlation technique previously mentioned has been employed to assess simultaneously the significance of each variable. By a process of cut and try, the several sets of data for each of the nine cities were related to one another, and a series of curves were developed from which a pattern of auto travel generated in the central business district can be determined for any city within the population range 50,000 to 600,000. One step in the graphic solution of this problem is shown in Figure 14.

The effects of the distance variable have been determined by studying the remaining variables by mile or ½-mile increments of distance from the central business district. Trip volumes produced in all zones at the prescribed distance in each city have been reduced to the average number of trips performed by each car registered in those zones on an average day. In Step 1 of the correlation study (Fig. 14) the average number of trips per car per day have been plotted against the average population-vehicle ownership ratio in those zones which generated the trips.

Ezekiel's method of graphic multiple correlation has been employed in succeeding stages of the correlation. A line is fitted to the data plotted in Step 1 and the variations from that line plotted, Step 2, against the cumulative proportion of the metropolitan-area



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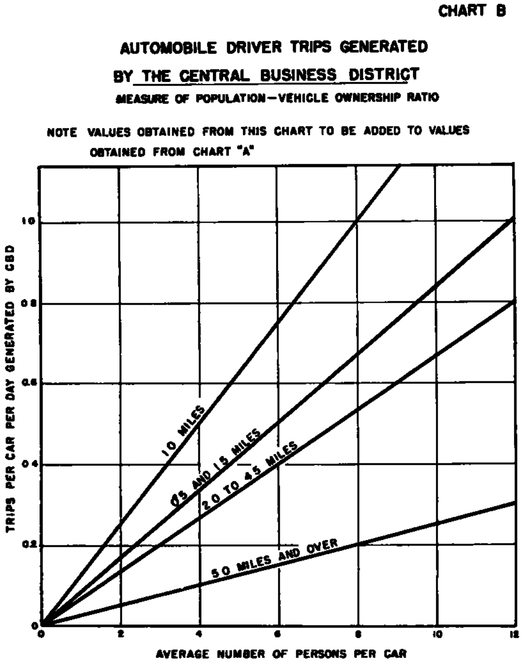


Figure 16.

population living within the prescribed distance (within 2 miles in this illustration). A line is then fitted to these data and the deviations from this line plotted, Step 3, against a scale representing metropolitan area population. A line is fitted to this last plot (in this case, a curved line), and the data examined to determine how well the variables tested have explained the generation of travel to the central business district.

If the curve drawn in the final step cannot be made to fit the data well, the process is repeated, trying different slopes of line in the initial comparisons which will effect the relationships of points plotted in succeeding stages. The curves shown in Figure 14 are a result of numerous trials which are related not only to the data shown on the drawing but also to data for shorter and longer distances from the central business district as well. The final step in Figure 14, fitting a curve to account for city size, results in a good correlation.

Correlations similar to Figure 14 were made for each ½-mile increment of distance from 0.5 miles to 4.0 miles from the central business district. Beyond 4 miles, population compactness ceases to be a factor and has been omitted. Data have been correlated to city size and car ownership by 1-mile increments from 4 miles to 7 miles and for trips generated at 9 miles (drawings not shown).

ESTIMATING INTERNAL AUTO DRIVER TRIPS GENERATED BY CENTRAL BUSINESS DISTRICT

Three charts have been prepared to show the relative effects of each of the three independent variables tested in the series of studies represented by Figure 14. These charts are illustrated in Figure 15 (effect of city size), Figure 16 (effect of ratio of population to vehicle ownership) and Figure 17 (effect of population compactness). The fourth variable, distance from central business district, is represented by a series of curves in each drawing.

In order to separate the several series of curves in a logical sequence (by increments of distance from the business district), an arbitrary series of scales have been worked

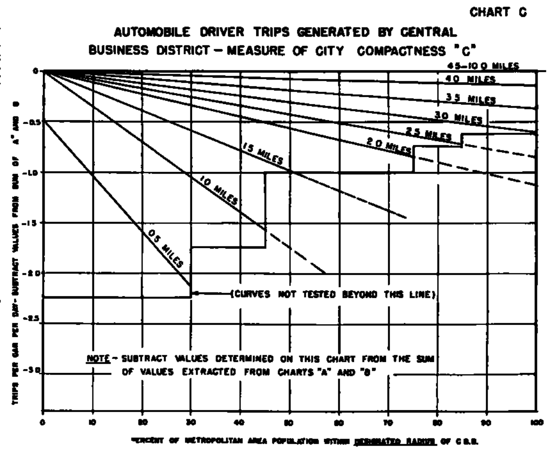
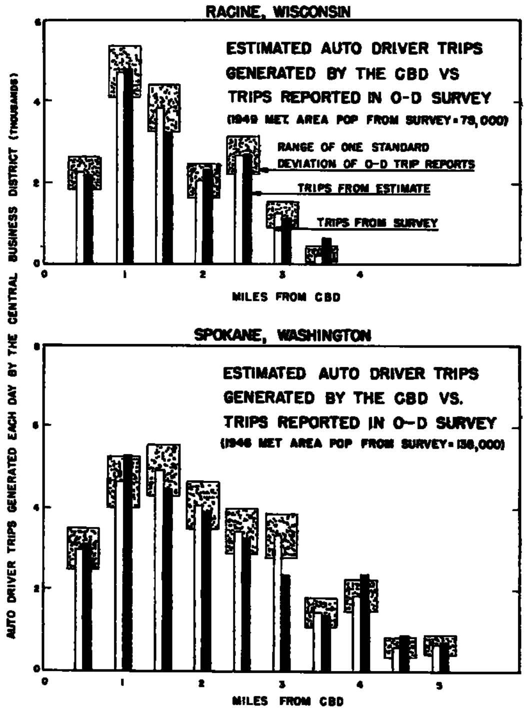


Figure 17.

out for the dependent variable (trips per car per day) which give positive values to city size (Chart A) and population-vehicle ratios (Chart B), but make population compactness a negative value (Chart C). These arbitrary scales are convenient for use in making estimates of trip generation, but by no means reflect the relative importance of each variable.

Data for any city in the population range 50,000 to 600,000 may be evaluated by these three charts (values based on data from the only city larger than 600,000 are regarded as tentative). Readings from Charts A and B are simply added together and their sum reduced by the value determined from Chart C. The result is the average daily volume of trips generated in the central business district by each motor vehicle regularly garaged in the particular zone or group of zones at the designated distance.



Figures 18 and 19.

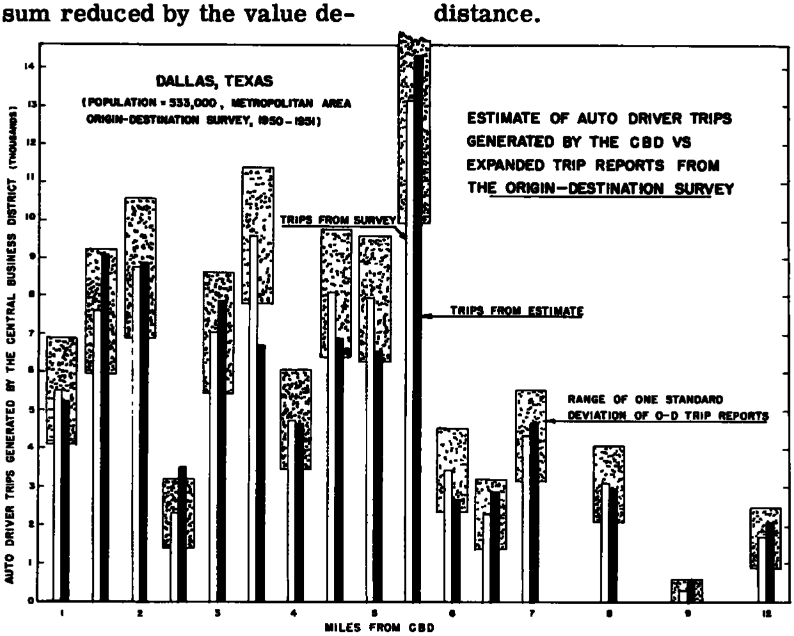


Figure 20.

DATA REQUIRED FOR ESTIMATES OF CENTRAL BUSINESS DISTRICT TRIP GENERATION

The information needed to measure the internal generation of automobiles by the central business district consists essentially of population and vehicle-ownership data. Evaluated by the set of charts just described, the pattern of residential termini can be quickly established. If this information is to be of most value to the traffic or planning analyst, a complex breakdown of the residential community is desirable—perhaps as many as 50 or 60 zones or tracts of nearly equal size or population. The population and vehicle ownership in each zone should be carefully determined (for this reason census tracts may prove to be a convenient base). The centroid of population distribution should then be established in each zone and the shortest distance between that centroid and the center of the central business district determined, as measured along existing streets. Population compactness and the ratio of population to vehicle ownership for each zone must also be computed. These data are sufficient to make the estimates already described.

A better estimate of residential termini can be made if the total number of central-business-district auto trips generated by metropolitan-area residents is known. A parking-turnover study conducted at curb and off-street facilities can supply this information, provided care is taken to ascertain the proportion of trips generated beyond the metropolitan-area limits. The known volume of internal central-business-district auto trips thus obtained may be compared with the total estimate derived from the graphic formula and the volume of movement ascribed to each zone raised or lowered in direct proportion to the difference between estimated overall volume and actual volume.

TESTING RELIABILITY OF CENTRAL BUSINESS DISTRICT TRIP ESTIMATES

Reliability of the estimating process described above can be determined by making estimates of central-business-district generation in cities for which O-D information is available as a check. Three cities were selected for this purpose, none of which was used in deriving the estimating formula. These cities, and their metropolitan area populations at the time of study, were Racine, Wisconsin, (78,000 in 1949); Spokane, Wash-

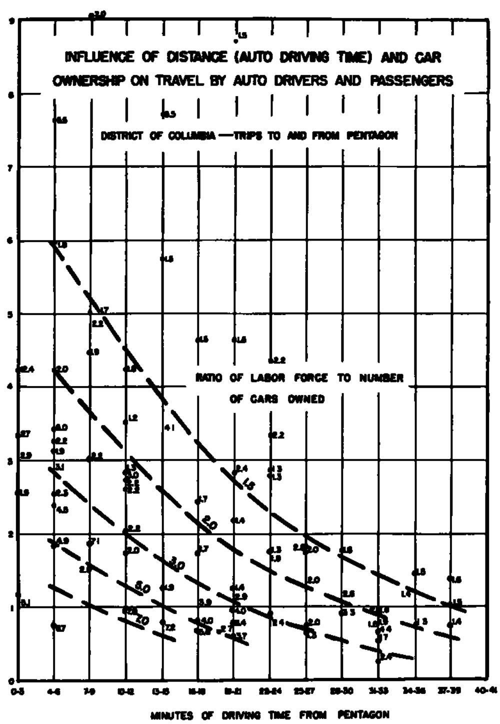


Figure 21.

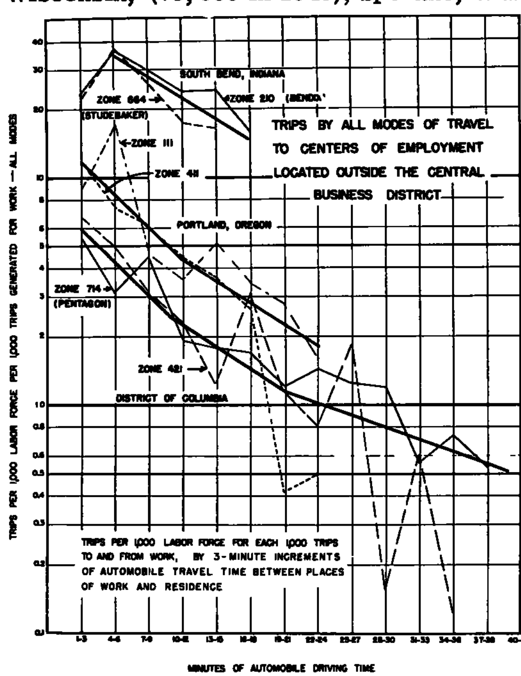


Figure 22.

ington, (138,000 in 1946); and Dallas, Texas, (533,000 in 1950-51).

Tests were carried out for estimating the average number of central business district trips performed by each car at each increment of distance from the central business district. An approximate standard deviation was established for the O-D trip reports at each distance and the difference between estimate and O-D reports computed in terms of standard deviation units.[4] These data are shown graphically in Figures 18, 19, and 20, where sample data and estimated volume have been plotted against a shaded area representing a range of one standard deviation. Estimates for all three cities appear to be about as reliable as the data obtained from home interview samples.

AUTO TRIPS TO WORK

The investigation of trips generated in the central business district has been subject to more attention in this study than has been devoted to trips with origins and destinations outside that area. The central-business-district study was undertaken earliest and was well developed before other land uses were investigated in any detail. The investigations of industrial and residential areas have been principally devoted to the application of variables similar to those used in the central-business-district study. On the whole, this approach seems to have been justified. Studies of individual cities show that the variables of distance (or travel time), car registration, population distribution, and city size are important factors in the generation of all internal auto travel.

Four broad land-use categories were considered when these studies were designed, and three of them were investigated. Auto trips which originate in residential areas may terminate in other residential zones, in the central business district, in a recreational area, or in industrial areas. Trips to recreational areas were not investigated specifically, although trips to neighborhood playgrounds, schools, etc., would generally be included in the residential-area category.

The term "industrial area" is an ambiguous one. Trips to factories, institutions and other large establishments are included in this designation, as used here. Most of such trips are generated by places of employment.

Figure 21 shows a family of curves fitted to data representing the ratio of population (labor force)[5] to vehicle ownership, plotted in terms of trips per unit of population against driving time to the Pentagon in Washington, D. C., and describe the approximate rate of trip generation from zones of various car ownership levels. The Pentagon attracts a larger volume of workers each day than any other area studied (about 40,000 trips per day). Although many discrepancies from the fitted curves are evident, the relationships shown are quite real. Many of the widest discrepancies are due to very small, unstable samples.

The data shown in Figure 21 are a rough measure of two of the four variables studied for central-business-district auto generation. A third variable, city size, has been examined in Figure 22 for travel by all modes.

Data for two industrial zones in each of three cities have been plotted here against minutes of travel time. A free-hand curve has been fitted to data for each pair of industrial zones to show the approximate rate of trip generation in each city. In every case the field data deviate considerably from the line of estimate. Such deviations are

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[4] A principal deficiency of the estimating technique described above, and the reliability checks made for three cities, is the lack of an adequate statistical measure of dependability. At this time it does not seem possible to make a correct evaluation of 0-D sample data, due to the decided bias introduced when underreported samples must be adjusted upwards. Without such a measure, assumption that the Gaussian law applies sets up an arbitrary scale for the comparison of synthesized data with the more conventional samples. This scale must serve for the present as a guide to the relative similarity of estimate and sample and should not be construed to define more precise values than that.

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[5] "Labor force" appears to be a more reliable basis for work trip generation than total population. Investigation of census data for Portland, Oregon, shows labor force to range from less than 40 percent to more than 60 percent of census-tract population.

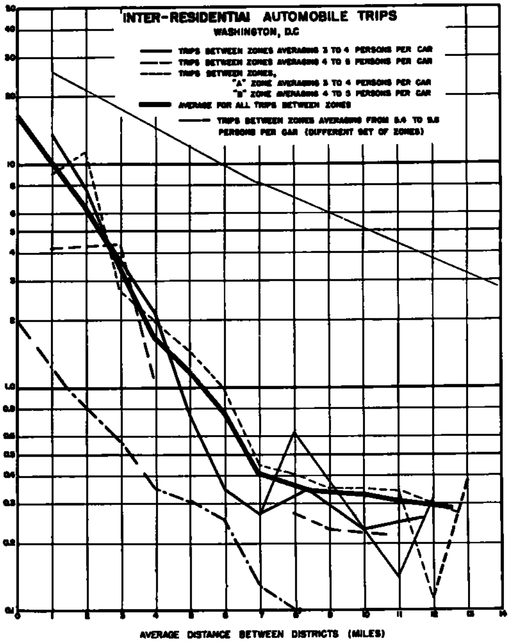

Figure 23.

generally of smaller magnitude near the industrial zone, where trip volumes are large and samples stable. In Washington, data for the Pentagon fit rather closely throughout the city, due to the large sample represented by the Pentagon. Data for Zone 421 lose stability at about 25 minutes distance.

In Portland the data for Zone 111 show a wide range of variation but shift above and below the line of estimate, the most extreme deviation occurring at 4 to 6 minutes from the zone. On the other hand, Zone 411 shows a steady rate of trip generation out to 18 minutes, when the sample becomes very small and unreliable.

In South Bend both sets of data fit rather well, considering the size of the community. Generation is measured in trips per 1, 000 labor force per 1, 000 trips made to the zone.

Washington, with twice the population of Portland, has twice as large a labor force and, therefore, generates from it at half the rate to provide each thousand workers to the Pentagon. South Bend with a fourth the population of Portland must generate at four times the Portland rate to provide a thousand workers at the plant.

The consistency with which this takes place is most impressive. The same degree of stability was not achieved when auto driver trips were examined alone, however, and it appears likely that another variable may have to be investigated. The population-compactness variable has been studied but does not appear to hold the entire answer.

Inter-Residential Auto Travel

Trips generated between residential zones have been subjected to a series of investigations similar to those applied to industrial work travel.

Two selected groups of districts in the Washington, D. C., metropolitan area were chosen for analysis. Twenty districts in which car ownership ranged from three persons per car to five persons per car were carefully selected to represent a cross-section of the metropolitan area. Another set of ten districts was selected in which ownership ranged from a low of 9. 6 persons per car to a high of 5. 4 persons per car. Most of these districts are within the District of Columbia.

In Figure 23, data from the 20 zones of high car ownership have been segregated into three categories. These are districts of high ownership ratio (three to four persons per car), relatively low ownership (four to five persons per car), and mixed areas (one of high and one of low registra-

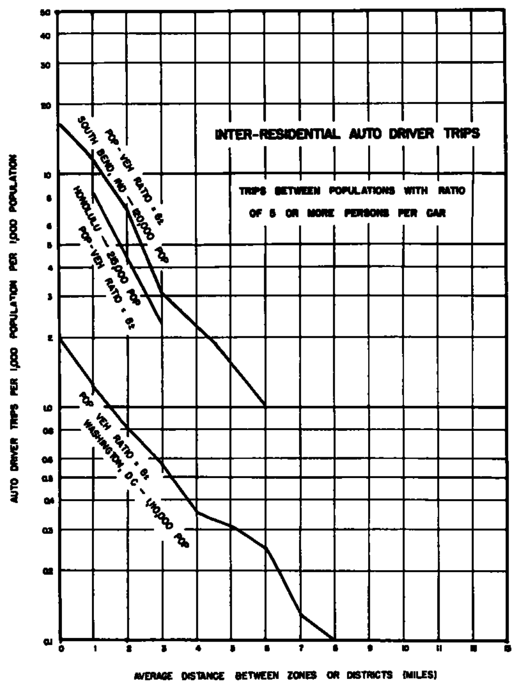

Figure 24.

tion). Trips in the latter category constitute the majority of movements and show the most consistent trend. In fact, they show a slightly higher rate of trip generation than trips between areas of high registration, but here again the sample is small and this difference is not significant. Travel between districts of low car ownership are generated at a lower rate.

When trip interchanges between the group of districts with very-low registrations are plotted, there can be no mistaking the importance of the ownership ratio. The slope of this line indicates an exponential decay pattern similar to the curve for all trips generated between the districts of high registration but at a rate very-much lower.

Although the rate of interresidential auto travel declines rapidly as trip length increases, the rate of decrease flattens abruptly at about 7 miles. There is no ready explanation for this, other than the possibility that this is a characteristic of the Washington area, since trips for all three categories exhibit the same tendency. Data are weak beyond 7 miles, in any event.

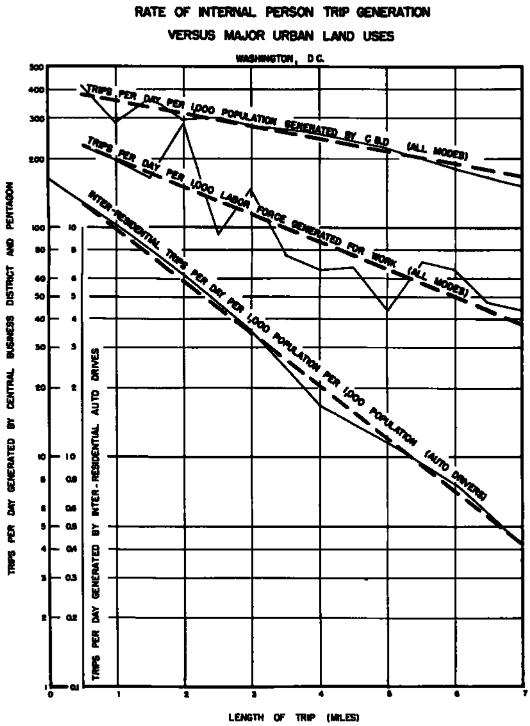

Figure 25.

In Figure 24, data for trip interchanges between zones of low car registration have been plotted for three metropolitan areas. In South Bend it was possible to study trips up to 6 miles in length. In Honolulu the zones of low registration are located near the center of the city, and study was limited to interchanges 1 to 3 miles in length (intrazone data were not evaluated). Trips in Washington extend up to 8 miles in length.

The rate of car ownership in all of the areas studied here is roughly the same. Note that the pattern of trip generation is quite consistent from one city to the next. Variable rate of trip generation appears to be closely related to city size. Since the trip opportunities of a population increase directly with population increase as discussed in the evaluation of work trips, it would seem that the pattern produced is a reasonable one.

Range of Trip Attraction Related to Land Use

One of the most-interesting results of the trip studies is the comparison of ranges of influence by land use types. Figure 25 shows the relative strength of trip attraction for each of the three land use categories studied in Washington, D. C. Trips by all modes of travel form the basis for these comparisons (inter-residential transit use is negligible).[6]

Travel to the central business district is maintained at a relatively high rate for many miles out from the center of the city. This is due, of course, to the unique quality of the central business district. Many types of service, trade, employment, and other features cannot be duplicated elsewhere in the community. In order to avail themselves of these unique qualities, the resident must go to the city center, regardless of his distance from it. He can postpone his visits and accumulate his errands if the trip is long, but he has no more convenient alternate. Trips by all modes to the Washington, D. C., central

[6] The contrasts would have been even greater if auto travel only had been shown since the curve for auto trips to central business district (Figure 10) is practically level, and the curve for work trip generation is probably flatter than the one for all modes. The latter has not been drawn, however.

business district are generated from 7 miles at about half the 1-mile rate.

Travel to places of work is not so restrictive as travel to the central business district. Most large centers of employment are still located near the city center, however, and there is need to travel several miles to reach any of them from outlying suburbs. Since many of the same skills are required in all large employment centers and since competition in the same labor market tends to stabilize levels of compensation, it is likely that many workers attach themselves to one of the more-convenient work centers. This would account for a more-rapid decline in work trips from the more-remote areas as against trips generated in the central business district. Industrial area work trips at 7 miles are generated at only a fifth the rate at 1 mile in Washington, D. C.

Interresidential trips greater than a mile in length are usually performed by car, because of relatively poor transit service between residential districts. Most interresidential trips are short, and the range of attraction to other residential areas drops off fast. This may be explained by the fact that each residential area is immediately adjacent to similar areas on one or more sides.

The opportunities for neighborhood services, amusement, recreation, visiting, school, church, etc., are numerous within a short range. More-remote areas offer virtually the same attractions, so that there is relatively little demand for interresidential travel of any length. The rate of interresidential trip generation at 7 miles in Washington, D. C., was found to be only one twenty-fifth of that at 1 mile.

Perhaps the most striking feature in Figure 25 is the consistency of the slope of the lines, each of which appears to conform to an exponential-decay pattern throughout its length.

Discussion

J. D. CARROLL, JR. —Wynn is to be congratulated for tackling such a difficult task. This is one of the most-meaningful papers yet presented on basic urban-travel patterns and their predictability. Reading, interpreting, and correcting various O-D surveys to a common base is a difficult job and one that has long been needed.

Wynn provides evidence of a reliable prediction of the number of trips, especially work trips that will be made in any urban area, and explores factors which can be used to predict trips between the central business district and other points in the urban area. This analysis is helpful in that it indicates variables associated with auto-driver trips. It is too bad multiple correlation was not used, instead of the nomograph-estimating procedure, to provide more-precise evidence of the effect of the variables used.

A test of Wynn's formulation interpolating from his charts to get the central business district auto driver trips in an area of 3 million population (Detroit) discloses that his estimates will be almost 1,000 percent high in such a large city. Therefore the ranges apply only to the cities studied.

Wynn has generally used the premise that residential characteristics can be the basis for predicting zone-to-zone movements. This presents a problem, since only 80 percent of all trips are to or from home (zone of residence). The other 20 percent cannot always be logically predicted on the basis of residential characteristics of the tract or zone of trip origin. For example, where he finds more CBD origins and destinations proportionately at the closer zones, proof should be developed that these are not due to intermediate stops by residents of the outer suburbs who are only performing some errand enroute to or from the central business district. In brief, all trip origins from a residential zone are not made by residents and, therefore, cannot all be predicted on basis of the characteristics of those residents.

A comment is offered, not in criticism of this paper (the best material so far presented), but in hope for the future. These facts should be synthesized into a theoretical explanation as to why these patterns are predictable. Only with this further synthesis can these numerous facts be organized into a body of tools to forecast the traffic effects of land-use change. Ultimately, it is possible that traffic flows can be approximated from population and land-use data. This paper represents a first step. Wynn is to be congratulated.

F. HOUSTON WYNN, Closure—Carroll is exceptionally well informed on urban traffic characteristics, and I appreciate the kind words he has to say about my paper. He is somewhat critical of my use of the nomographic technique and perhaps a few words of explanation are called for. In my opinion the data used were too few to definitely establish the precise effect of the different variables used, or even their order of importance. When more data are at hand, I expect to develop more-precise evaluations.

One cannot caution too strongly against the misapplication of the CBD trip charts. In addition to the hazard of city size that Carroll points out, there is also the problem of defining the limits of the CBD to which trip estimates will apply. Caution must also be exercised in applying these curves to areas of lower population-vehicle ratios than were found in the cities from which they have been developed. The curves have been prepared to illustrate the consistencies of traffic behavior among a diverse group of cities; the fact that they can be used to estimate traffic behavior in other cities must be regarded, for the time being, as incidental. The relationships encourage me to believe a practical predictive formula will soon be developed.

The paper is entirely too brief to cover all of the many aspects of urban travel which have been investigated by our studies at Yale. We have found, as Carroll suggests, that about a fifth of all internal trips cannot be directly related to the residential units. We have developed some measures of this travel, but there is much yet to be done before we can describe all of this travel with confidence. Carroll gets to the basic problem whe[n] he points out the need for a theoretical explanation upon which the entire pattern of urban travel can be based. I am confident that this overall concept is not far off.